Development of a Serious Game to Improve the Teaching of Chemistry

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ABSTRACT

It is very common the lack of interest and focus of the students in the learning process. In chemistry, due the abstraction to understand concepts involving microscopic entities, the disinterest may become more o recurrent if the students don't stay focused and motivated to learn. To motivate and try to make learning fun, we have developed the World of Chemistry, a playful platform, where students test their knowledge of chemistry while exploring a virtual world in order to improve the teaching of chemistry. The platform was tested with 30 volunteers to analyze its motivational and playful impact, which had a great performance and acceptance. It was also possible to analyze the usability of the platform and thus propose improvements.

KEYWORDS

Serious Games;
Learning;
Virtual Reality;
MDA Framework.

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1. INTRODUCTION

Disinterest and attention deficit have great recurrence in school education (Leal *et al.* 2011). This fact can be associate to the poor teaching materials, as appointed by (Laranjeira *et al.* 2009), and agreed by (Aparecida *et al.* 2009), in the diversification of the classes. Many of the chemistry concepts have their explanation based in microscopic entities, requiring focus and attention to simplify this abstraction, a fact that makes learning more susceptible to disinterest (De Quadros *et al.* 2011). As an alternative to encourage students to concentrate and motivate them in the learning process, it has become common to apply playful elements in teaching.

According to (Giasolli *et al.* 2006) immersing a student in a virtual environment with similar characteristics to the real world, allowing the student to test hypotheses and prove that they are true is one of the most effective ways to teach. Applying gamification in a virtual environment, it is possible to transform the frustration of failure into necessary part of gaining knowledge (Lee, and Hammer 2011), a feature that makes Serious Games an interesting alternative to improve teaching in classroom.

Serious Games are a branch of games and can be defined as productive games, which focus on transformations instead of just fun. The transformations can be applied to skills improvement, adaptation to the environment, and with the focus on teaching: the understating of phenomena (Mouaheb *et al.* 2012). Serious Games cover a wide variety of applications. In health, there is *Gameterapia* as example: the practice of physiotherapy using a ludic platform that immerses the participant in a virtual environment, through the use of the Kinect, a motion capture tool; thus, using fun to ease the discomfort of therapy (Alflen *et al.* 2016).

As a free playful solution with motivational aspects, the *World of Chemistry* platform was developed. The main goal of *World of Chemistry* is to provide a knowledge test to be applied in the classroom, in order for the player to review the contents of chemistry learned, and to improve and to diversify the learning process at chemistry classes. The purpose of this paper is to describe the *World of Chemistry* platform, its game design process and how it behaved by means of an initial study.

2. GAME DESIGN

Game Design is a decision-making process that occurs throughout the Game Development. This process is more present in the planning stage, where it is necessary to define and mature the structure of the game. It is important that the Game Design process of a Serious Game respects a transformation context, which in this study is

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divided into three aspects:

1. Purpose: Improve the teaching of chemistry by a playful and diversified solution;
2. Approach: A knowledge test of the contents learned previously in the classroom;
3. Contents of Chemistry supported: Isomerism, Structural Theory, Chemical Bonding, and Molecular Geometry.

To support the Game Design process of the *World of Chemistry*, the MDA Framework was applied. This Framework has the purpose to facilitate the design process by understanding the games through three aspects: aesthetics; dynamics; and mechanics. According to (Hunicke *et al.* 2004), the aesthetics are the emotional responses of the player when interacting with the game, the dynamics are the interactions which promote the aesthetics and the mechanics are the components of the game that allow the dynamics. Based on the transformation context, the established aesthetics are:

- Sensibilization: The emotional state of the student is very important in the learning process (Lima *et al.* 2011). In this way, it is proposed that the player be sensitized through a narrative to encourage him to fulfill his goals;

- Immersion: Focus is an important aspect of the flow state (Schell 2013), which is the state responsible to disconnect the player from reality and immersing him in the game (Zichermann *et al*. 2011). To encourage the player to keep his focus and avoid real-world distractions, the platform stimulates a feeling of immersion in the virtual environment;

- Progress: Students performance in testing their knowledge is directly related to their progress on the game. Stimulating the feeling of progress may encourage them to improve their performance in case it is not going well (Werbach *et al.* 2012);

- Danger: It is one of the most common feelings in games. Danger can be considered as a negative motivator due the possibility of stimulating bad feelings as anxiety and frustration due the failure (Chou 2015). However, if stimulated with caution, it can enhance the player's attention;

- Conquest: The feeling that the player is making good progress is an important motivator (Zichermann *et al*. 2011); thus, its aim is to stimulate the player to perform well by achieving defined goals.

Having the aesthetics defined, the Serious Game can be matured by defining the dynamics and so the mechanics. The dynamics and

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mechanics incorporated to the Serious Games will be explained in the next section as the platform is introduced. Besides MDA, it was defined by Game Design that the test of player's knowledge would be realized by the interaction with challenges through the game experience.

The challenges were defined by using the brainstorming technic in analysis of a set of questions of chemistry contents selected from Brazilian higher education ingress tests. The analyses consisted in refining the similar characteristics between the questions on the same contest and adapting them into regular game challenges. All the Game Design process regarding chemistry concepts were developed with the support of a Chemistry Teacher to guarantee the consistence of the concepts.

The experience of using a Serious Game is characterized as a human-computer interaction and can be analyzed through usability tests (Barbosa *et al*. 2010). All the components developed by the Game Design were tested in two ways. First, in a critical analysis of the usability on a single component by a person involved in the planning process. Second, in the game flow with all the components integrated, which consisted with the participation of two testers without previous contact with the game. After all the detected usability problems were corrected, another usability test of the game flow was realized with the participation of a chemistry teacher involved, in order to guarantee that the game was ready to be applied. After the verdict of the teacher, the game was applied in the initial study.

3. WORLD OF CHEMISTRY

Characterized as a fantastic-themed Serious Game, the *World of Chemistry* is a virtual reality application that stimulates the feeling of immersion by representing the player as an avatar capable of movement (using the arrow keys) and interaction, in a three-dimensional (3D) virtual environment in a first person view (by using the mouse to control the camera) The first person view can be seen in Figure 1. A set of challenges are proposed to the player test his knowledge while participating in an adventure. The platform development utilized Unity 3D, a set of tools that facilitate and abstract the development of games and is distributed to the Windows operating system.
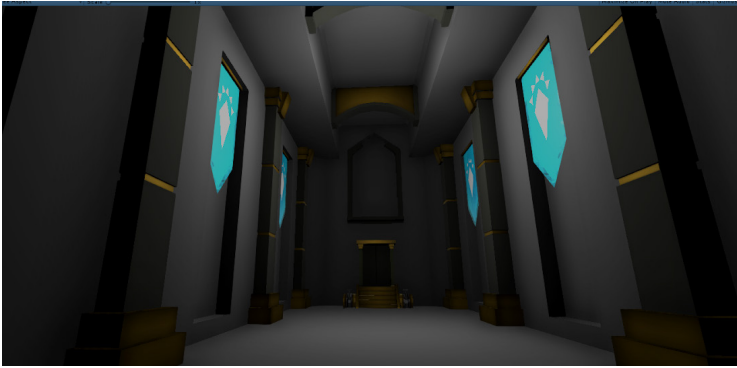
Fig. 1
First person view of the initial
level of Lewis Mine phase

The fantastic theme in platform is incorporated by an emotional narrative with the objective of stimulating the sensibilization feeling defined on MDA. The narrative introduces a character which his mother is sick and to heal her, he seeks the help of an alchemist in his village. The alchemist proposes to help him with a healing potion. However, he lacks two ingredients: a carbon and an oxygen atom. Thus, the player must venture into the game to get these two atoms in them respective phases.

Introduced by means of cinematic based in two-dimensional (2D) images, text and song, the narrative is divided in two main parts and two auxiliaries. The first main cinematic is responsible for introducing the narrative and clarifies the main goals of the player: to collect the atoms. The second main cinematic is the closure, which is presented after the player completes his goals. There are also auxiliary cinematic that are presented after the player collects each atom, in order to demonstrate to the player, the conclusion of each goal. Examples of 2D arts used in the cinematic can be seen in Fig. 2 and 3.

The phases were developed in a way that the environment refers the characteristics of their own atom. The first phase is the Mine of Lewis, an excavation mine divided into four levels, each of them is a hall, and the carbon atom, represented by a large diamond, can be collected at the end of the last level. The second phase is Aeris, a flying city divided into three flying platforms, each as a level, connected to the others by teleportation portals, and the oxygen atom is represented by a sphere with wings. The representation of the atoms is just aesthetic, to turn them into notable objects.

Fig. 2
The alchemist

Fig. 3
The main character and his mother

The challenges proposed in the *World of Chemistry* are based into three structures; the first one is questions and answers. This structure challenges the player, through a custom screen, to answer a question by selecting one of your answers. The custom screen is loaded by interacting with a 3D object which represents the challenge. To solve the challenge in this structure, the player just has to select the correct alternative and confirm.

The challenges of questions and answers have two approaches, one for questions of all the contents of chemistry supported (general approach) and the other just for isomerism (isometric). Each approach presents a different interaction object and screen in order to soften the monotonicity and allow in the isometric approach the use of images, which is an important aspect of the visualization of the chemical components in the questions. The general approach is represented by a Lever, as can be seen in Fig. 4 and 5, and the isometric approach by a display, as in the Fig. 6 and 7.

Fig. 4
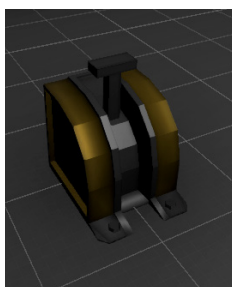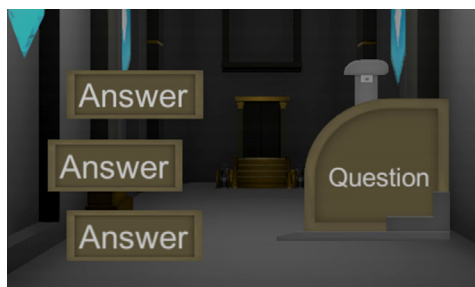Lever approach custom screen.

Fig. 5
Lever activator object.

The second challenge structure is fitting, where the idea is the player to catch an object and fit it in a structure denominated totem. The fitting object can be an atom or a 3D structure of chemical compounds. A panel, located above the totem, is responsible for specifying which object must be fitted in the totem, as demonstrated in the Fig. 8. This structure is composed by three approaches:

- Electronegativity: presents a totem and various atoms and the player must select one of the atoms and fit in the totem according to the required electronegativity (low or high);

- Chemical bonds: presents two totems, each one is an atom of a chemical bond and the player must fit the atoms that, based in their electronegativity, generate the required chemistry bond (Ionic or Covalent);

- Molecular Geometry: presenting only one totem, where the player must select the chemical compound in its correct 3D form, based on the Lewis structure presented in the totem's panel. An example of this approach can be seen in the Fig. 8 and 9.

Fig. 6
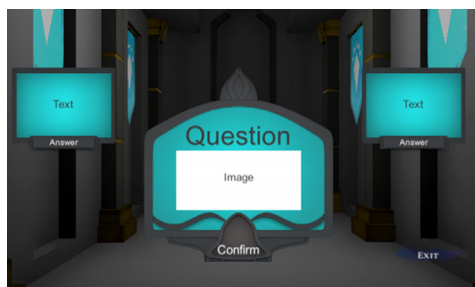Isomerism approach custom screen

Fig. 7
Isomerism activator object

The last challenge structure is called impact and is based on the idea of target shooting. Using a rune, an object capable of casting a spell, the player must aim the spell on a target and hit it to solve the challenge. Each target is a sphere with a Valence Shell Electron Pair Repulsion (VSEPR) model inside and only one rune is associate to each VSEPR model; thus, only one enchantment will solve each challenge. The runes can be selected by a panel available to the player.

The challenges have their own dynamicity and this it is important in the definition of the sequence of challenges in the phases. The dynamicity is defined by the player's response time from the moment that the challenge is proposed to the moment it is answered; thus, the questions and answers structure is considered not very dynamic, the fitting has medium dynamicity and the impact more

dynamic. The sequence of challenges in *World of Chemistry* was made in order to avoid repetitions of less dynamic challenges and thus, avoiding player to get tired.

To ensure that the challenges are clear to the player, the platform has tutorial screens, which are loaded automatically in the first contact with the challenge. These screens have a brief description of the challenge, the contents of chemistry that the approach supports and how to interact with 3D objects in order to solve the challenge. Also, we have developed tutorials to present the variations of the 3D models of the challenges that can happen from one phase to another, with the intention of notifying that it works in the same way.

All the challenges have a score mechanic applied to stimulate the sense of progress defined on the MDA. The score mechanic works with a base value and a bonus, so regardless of the outcome of the challenge, the player will always receive a score when solving it. The bonus is a value proportional to the number of attempts to solve the challenge: if it is solved on the first attempt, the player will receive the total value, if the number of attempts exceeds a limit, the bonus value is zero. The player's score is displayed throughout his experience by a Heads-Up Display (HUD). By allowing the players test more than one hypothesis in the challenges, besides testing their knowledge, it is possible to earn knowledge by the trial and error (Giasolli et al. 2006).

Fig. 8
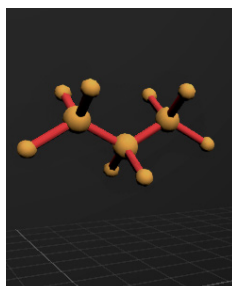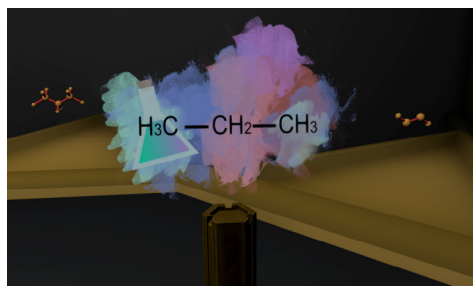Totem de encaixe com a abordagem de Geometria

Fig. 9
Objeto de encaixe da Figura 7

The platform proposes fall obstacles and attributes lives to the player to stimulate danger. The fall obstacles are basically precipices as can be seen in the Figure 10, if the player falls; he loses a life and suffers a penalty based on the remaining amount of lives. If the amount is greater than zero, the player will return to the phase in a location where all past challenges have been solved and all ahead

are pending solution. If the amount is equal to zero, the player will be redirected to an end game screen that can restart the phase. The initial number of lives is set to 5 and is presented to the player by a HUD.
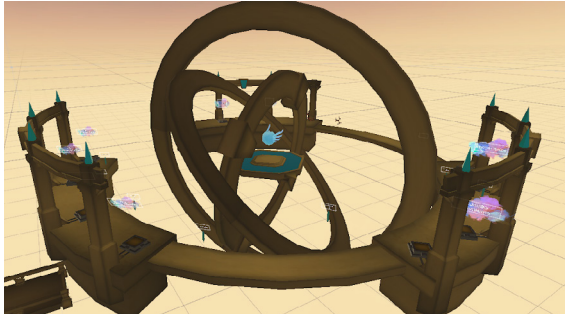

Fig. 10
Fall obstacles of Aeris phase.

The fall obstacles are present in all the game experience in way to define, among other obstacles, the player's route from the beginning to the end of the phase. To overcome the precipices, the player can jump over it if the distance between the platforms of a precipice is short but, if the distance is too long, there is a hidden or broken bridge that turns out or gets fixed by solving the nearest challenges. The other obstacles are closed doors and gates (Fig. 11) that allow the player to proceed on the route by solving challenges.

The conquest feeling is stimulated by the use of badges, which are visual representations of achievements. Each achievement was developed to reward the player for his performance and is defined by the criteria of player's number of lives and failed attempts in challenges. Motivational badges were also developed which are received at the end of each phase regardless of his performance as a motivator to continue playing.

Fig. 11
Gate obstacle blocking player's route.

4. INITIAL STUDY

An initial study to analyze the potential of the platform as a playful test of knowledge was carried out. The study consisted with the participation of 30 volunteers (including 6 teachers) with a mean age of 23 (the oldest participant with 36 years and the youngest with 16). The participants are not exclusively involved in chemistry fields; they include 10 areas of knowledge defined by The Brazilian National Council for Scientific and Technological Development.

The study was mostly performed remotely, and the methods consisted in provide the application on the volunteers' personal computer and let them play the game freely after a general explanation of the study and the basic commands of movement and interaction. After finishing the game, the volunteers were submitted to a form to describe their experience. The form consisted in questions on a scale of 1 (weak) to 5 (strong) about the playful aspects of the experience, the motivational influence of the mechanics and how the platform suits as a knowledge test. The form also allowed the participants comment about their experience.

Throughout the application we have noticed that the volunteers were very interested to participate in the study, of which chemistry students stood out appearing very excited about the idea of a Serious Game as auxiliary tool. Overall, the platform was well approved as a chemistry knowledge test by all of the 30 participants (4 or 5 on the scale), of which only two did not describe the experience as fun (weak influence). These two participants are not from the chemistry field, which may have affected the experience due the difficulty in responding the challenges. However, the other 14 participants that are not from the chemistry field described their experience as fun.

The 3D immersive approach was described as more engaging and divergent from common educational game applications, however, many of the participants reported that the approach did not perform well on their computers and some applications (out of the 30) could not be performed due the computers did not support the applications.

About the motivational effect of the mechanics, the score had a good influence (4 or 5 on the scale) on 80% of the participants, who reported that were motivated to have a better performance in order to get a good score. This motivation can be associated to the familiarity of the volunteer with the test scores in regular education. The badges had influence (more than 3 on the scale) on 70% of the participants, who said felt motivated to obtain exclusive badges. The resource of the narrative presented a positive impact on the game, being approved by 93% of the participants that affirmed

like the resource. Although the narrative motivational effect had a good influence on only 19 participants, that wanted to fulfill the goals in order to help the main character heal his mother. All the players had the goals of the game clarified by the narrative.

The participants reported that the platform allowed them to identify which contents of chemistry they had more difficulties, an important feature for reflect the player's self-knowledge. When questioned if it is interesting to use the game as an evaluation method for the classes, 86% of the volunteers considered the idea interesting, which included all the participating teachers.

5. CONCLUSIONS

Through the results of the initial study, it can be concluded that the platform provided a playful experience to the majority of the participants and the mechanics provided a good motivational influence in a considerable number of participants, which are important aspects of the Serious Game and its transformation. Even based on exclusively contest of chemistry he platform demonstrated a good engagement with participants without much knowledge in chemistry, as they also affirmed had a fun experience.

It has been realized that Serious Games should be developed to guarantee good performance in machines with few resources due the variety of the target audience. If possible, it is preferable to develop an application based on 2D environment to facilitate platform compatibility or a 3D environment optimized as much as possible.

As future improvements, the possibility of integrating external questions to the platform is already being analyzed to allow teachers to customize the game with their own questions; the possibility to generate a report on participant's experience: including questions that are wrong and plots that the player had more difficulty in order to make the platform more precise as an evaluation method of the student's knowledge and at least a menu that allows the player to customize the move and interaction commands as well as a screen to access the challenge tutorials.

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