

LeMo

Studying Chemical Molecular Structures through Gaming

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Abstract: The present work's main contribution is the description of a first experiment to create a virtual chemistry lab to be used at university level based on games instead of the traditional chemistry virtual labs based on experiments. The paper starts with the motivation to use games as a teaching-learning process and with the reason for choosing Lewis formulas and VSEPR theory to make a first experiment. Previous works, with emphasis on web solutions for Chemistry and the role of emotions in the learning process are then presented. The architecture of LeMo, the developed game, is described together with a detailed explanation of its operation. The paper ends with a summary of the experiment's results, which indicate that gaming may be a good strategy for motivating students to study Chemistry.

1 INTRODUCTION

1.1 Motivation and Objectives

In order to improve students' evaluation results, the Chemistry Scientific Area within the Systems and Informatics Department was interested in developing a virtual tool that could allow students to practice different contents. During the requirements analysis and specification step of the development process, the creation of a Chemistry Virtual Lab, that students could use autonomously, was proposed.

After a brief study of the available e-learning materials (Rekkedal et al., 2003); (Bottentuit et al., 2006); (Espinilla et al., 2010); (Allen et al., 2008, 2010) and of previous experiences within the Chemistry Scientific Area it became clear that several issues needed to be addressed prior to the development of any serious experiment. To us the most important issues were:

1. Which objectives should be considered for such a platform: to improve the evaluation results? To facilitate the learning and practice processes? To give students an environment where they would practice for longer periods?
2. Depending on the specified goals, a strategy had

to be defined. Three main options were identified: cloning existing virtual labs, simply giving the links to the best ones already present in cyberspace or developing a new one.

The creation of an engaging environment was established as the main objective. Considering that the two first strategies had already been implemented on the EST Setubal e-learning platform¹, and prior to engage in the development of a full environment, we decided to test the strategy of learning through gaming.

Taking the previous statement in consideration we may say that the aim of the present application is to provide a new method for practicing the writing of Lewis formulas and applying VSEPR theory, pointing students' mistakes in real time and in a pleasant way, in order to motivate students not to give up when studying these subjects.

Note that only on-line and completely free of charges solutions were considered during this work, in order to minimize costs both for students and institutions.

¹<http://moodle.ests.ips.pt/> (accessed 2011/Dec/08) Please notice that all links and Google queries quoted in the present work where last accessed and reviewed on this same date.

1.1.1 Why Lewis Formulas and VSEPR Theory

Molecular Structure is a compulsory chapter in any introductory course of Chemistry. The most elementary way to represent a molecule is using its Lewis formula, which shows all chemical bounds between atoms. However, and by itself, a Lewis formula doesn't give any information about the geometry of the molecule, which determines several properties of the corresponding material (boiling point, viscosity, etc.). The easiest way to determine a molecular geometry from a Lewis formula is by applying the Valence Shell Electron Pair Repulsion theory, VSEPR – a model used to predict the shape of individual molecules based upon the extent of electron-pair electrostatic repulsion. Despite the simplicity of these two subjects, students frequently find them boring, especially if their graduation areas are not in Chemistry.

Usually, students study these subjects by solving exercises on paper and comparing the obtained structures and geometries with the ones reported on the solutions section. This method is often frustrating as one single mistake is enough to lead to a completely wrong structure and/or geometry. As it is not easy for a student to identify the mistake by himself, he usually gives up.

The Chemistry Group first attempt to overcome this problem was the implementation of an interactive multi-choice questionnaire at the moodle based EST Setúbal e-learning platform¹. As the available wrong answers were based on the students most frequent mistakes, a tip popped out whenever a wrong answer was given, helping the student to find the right option.

Implemented at the Oxford Universal Virtual Chemistry Lab (Table 1) there is an application for attributing geometries to molecules (from a database of 20 molecules). Whenever the answer is right, the molecule 3D representation appears, helping the student to visualize its molecular structure.

The existence of these two applications also contributed for choosing Lewis formulas and VSEPR theory as contents for the present game.

1.1.2 Why Gaming?

From the last two decades of the past century on, brain sciences have developed deep studies on the role of emotions in conscience (Damásio, 1994). These studies changed the understanding of the relations between perceptions, emotions and the learning processes (Damásio, 1999).

During the Middle Ages, when no registration of

land properties existed, it was a common practice to choose a boy to witness land transactions. At the moment of the transaction and in the presence of the full audience, the boy was strongly hit in the face. It was empirically understood that the boy would remember that day for all his life and would identify the landlord, in case of conflict.

Nowadays this practice is no longer used. Nevertheless it is still well accepted that living a strong emotion contributes to a better memorizing process. Indeed, (Damásio, 2010) has recently proposed a brain perception and memorization model based on the relation between perception, images and emotions. For what this paper is concerned, do consider the concept of “Images” as in (Damásio, 2010), pg 36: *“The brain maps the surrounding world [including the whole human body], as well as its own functioning. These maps are experienced as images in our mind. So the term “images” refers not only to visual images but also to images that came from any other sense, like audition, visceral or tactile as a few examples”*.

It is also worth mentioning recent works in Affective Computing, pioneered by (Picard, 1995). According to (Shen et al., 2009), *“the influence of emotions on learning is still under-emphasized. Recently, a growing body of literature [in Affective Computing] has begun to espouse the central role of emotion to any learning endeavor and outcomes, especially in online learning”*.

Although Affective Computing studies are still in progress, it is possible to assume that gaming, that raises emotional states, should improve students' learning capabilities.

2 PREVIOUS WORKS

2.1 First Attempts

Considering the discussion and definition of e-learning presented by (Tavangarian et al, 2004) we may consider that the use of e-learning in Chemistry began almost half a century ago. Indeed (Yoshimura, 2006) refers its introduction in Japan in the 1980's. In USA it is consensual that PLATO² (Programmed Logic for Automated Teaching Operations), developed in the 1960's, was pioneer in computer assisted education. The earliest references to its use on Chemistry can be found in (Smith, 1970) and (Shacham et al., 1981). In Europe, and according

² [http://en.wikipedia.org/wiki/PLATO_\(computer_system\)](http://en.wikipedia.org/wiki/PLATO_(computer_system))

with (Hebenstreit, 1980), research in computer assisted learning started in the early 1960's in several French Universities. Nevertheless, the earliest references to its consistent use in Chemistry are found in the UK, associated to the project Computers in Teaching Initiative (Gagan, 2008), in 1989.

The number of e-learning products (or claimed as such by its developers) has grown exponentially since then (Casher et al., 1998), as illustrated also in (Table 1). Note that the numbers in (Table 1) also include items such as papers, reports, videos, images, and other applications. The huge number of web pages dedicated to Chemistry is an indication of the relevance of information technologies in the Chemistry learning process and corroborate the statement that "educational technology is now widespread in Chemistry teaching" (Gagan, 2008); (Wodward, 2008). In fact, (Gagan, 2008) is a review on the chemistry learning experience in the UK, so its generalization to Europe or to the world should be made with great caution. Nevertheless, if before the Bologna Process³ University Curricula across Europe were very different, today the situation is much more uniform. Moreover, we can see that their conclusions are in line with the results shown in Table 1.

Table 1: Quantity of results returned from a few Google queries.

Google Query	# Results
"e-learning in chemistry"	22 200
"Chemistry Virtual Lab"	22 200
"Chemistry Games"	116 000
+chemistry +e-learning	9 960 000
+Chemistry +"Virtual Lab"	1 110 000
+Chemistry +Game	70 000

2.2 Contemporary Web Solutions

After the global dissemination of web access, it is a common practice to use standard platforms as a support for e-learning activities⁴. According to (Kahiigi et al., 2008) these platforms may be described as:

1. Learning Management Systems (LMS): a whole range of information systems and processes that contribute directly or indirectly for learning and for the management of that learning. They are primarily

developed to provide online learning services for students, teachers, and administrators.

2. Content Management Systems (CMS): developed to facilitate the collaborative creation of contents, organisation, control, and to manage the publication of documents in a centralized environment.

3. Learning Content Management Systems (LCMS): web-based systems that combine management and administrative functionalities of LMS and CMS for author approval, publishing, and management of learning contents.

Being a recent classification that is used by a large number of different research & development areas and users, the concepts, acronyms and definitions proposed by these authors should not be seen as a final taxonomy. Just to give a practical example of such differences, (Kahiigi et al., 2008) states that moodle is an example of a CMS (and CMS stands for *Content MS*) while moodle.org defines itself as "*a Course Management System (CMS), also known as a Learning Management System (LMS) or a Virtual Learning Environment (VLE)*".

2.2.1 Web Solutions for Chemistry

The number of web pages dedicated to Chemistry is huge and includes many different applications (Georgious et al., 2007), such as repositories of theoretic materials, quizzes and questionnaires, detailed descriptions of experiments, mechanisms of chemical reactions, periodic tables, virtual laboratories (Table 2), or games repositories (Table 3).

2.2.2 Virtual Laboratories

Considering the meaning of these two words:

1. Laboratory: a facility that provides controlled conditions in which scientific research, experiments, and measurement may be performed⁵.

2. Virtual: this term has been defined in philosophy as "that which is not real" but may display the salient qualities of reality. The use of the word virtual for computer simulation of reality is not recent. The Online Etymology Dictionary reports that the sense of "not physically existing but made to appear by software" appears as early as 1959⁶.

the concept of "Virtual Laboratory" should simply qualify facilities that are not real but may display the

³ <http://www.bologna-bergen2005.no/>

⁴ According with <http://moodle.org/sites/> there are 72105 active sites registered in 223 countries.

⁵ Source: <http://en.wikipedia.org/wiki/Laboratory>

⁶ Source: <http://en.wikipedia.org/wiki/Virtual>

salient qualities of the reality, to provide controlled conditions in which scientific research, experiments, and measurements may be performed.

However, as shown from the few examples described in Table 2 and as already reported by (Georgious et al., 2007), only a few “Virtual Laboratories” actually allow virtual experiments. In fact, the concept of Virtual Laboratory is used by the Chemistry community for web sites that provide different kinds of resources, ranging from theoretical material, to questionnaires (that may be in a game format or not), demonstrations of experiments or even detailed experimental procedures.

Just to mention some of the selected sites, the Portuguese “Laboratório Virtual de Química” developed by Minho University is a depository of supporting information (materials & methods, procedures, queries, etc.) to be used by the students before their experimental lab classes. The Virtual Chemistry Lab, from infoPlease, is a completely different application, as it provides the possibility to execute several experiments online, representing what is occurring at the molecular level; this site can be used both by students (to improve concepts) and by teachers (to better illustrate these concepts to their classes). Virtlab, that claims to have users registered from 100 nations, can be seen as a good tool to illustrate theoretical concepts (during a class, for instance), or to compare with calculations results.

2.2.3 Virtual Reality Chemistry Laboratories

Virtual Reality has to be considered as a valid option for the integrating environment of the future Virtual Laboratory. It exists already some Literature concerning Virtual Reality applied to Chemistry, ranging from overviews and tutorials about how to develop such labs (Casher et al, 1998), to a set of already implemented Virtual Reality solutions (Georgiou et al, 2007); (Pérez et al., 2009). Augmented Reality solutions (Azuma, 1997); (Braz et al., 2007) are also worth to mention, as significant progresses have recently been made in this field (Núñez et al, 2007).

However, while a Virtual Reality environment is seriously being considered to be used in the future Virtual Lab, the use of an Augmented Reality environment is out of the question, mainly because of economic and technical reasons.

2.2.4 Chemistry Games

A simple Google query on Chemistry games gives from 70E3 to 116E3 results (Table 1). These games

have, however, to be divided into games that really require or illustrate some Chemistry, and others that only use Chemistry as a theme or scenario, requiring no real knowledge in the subject. In (Table 2) games belonging to each category are presented. If we only consider games that require an advanced level of knowledge (Keck, 2000) we can state that most of them are generally based on questionnaires, whether a “time-attack” strategy is present or not.

Table 2: A few examples of claimed “Virtual Laboratories”. Under the item “Demos” we include, tutorials, theoretical material etc.

Name	URL	Chemistry Materials	Experiment	Quizz	Demo
Virtual Chemistry	http://www.chem.ox.ac.uk/vrch/emistry/	<i>i)</i> Movies of reactions between salts and reagents. <i>ii)</i> The reagents of an organic reaction appear and the student has to draw the curly rows to indicate the mechanism of that reaction. The application answers back, saying whether it is correct or not and giving tips in the second case. <i>iii)</i> VSEPR: The program shows one molecule, from a list of 20, and the user has to select its molecular geometry from a list. In case it is correct, it shows a 3D representation of that molecule.	Yes	Yes	Yes
VLabs	http://vlabs.uminho.pt/quimica/quimica.html	Presents a list of experimental works, including material & methods, proceedings, safety instructions and movies showing the experimental procedures or illustrating particular techniques.			Yes
Lab Virtual de Química	http://www2.fc.unesp.br/lvq/Menu.htm	Description of several experiments: involved materials and procedures.			Yes
Virtual Chemistry Lab	http://www.infoplease.com/chemistry/simlab/	Illustrates several kinds of reactions at molecular level. It is very interesting to illustrate the role of each molecule during a chemical reaction in solution.	Yes	Yes	Yes
Virtlab	http://www.virtlab.com/main.aspx	Animations of several experiments showing the evolution of several data in time (concentrations, pH, temperatures, etc.)			Yes
Hi hydrogen	http://library.thinkquest.org/11430/research/index.html	virtual experiments. The student virtually “makes” the experiment and takes conclusions.	Yes	Yes	
Electronic Homework Pages- CSUDH Chemistry Dpl.	http://chemistry2.csudh.edu/homework/hwintro.html	Exercises to do at home. At the end the student puts his name and the name of his instructor. We believe each instructor has access to his students' scores. It is not a game. It is just one more source of exercises to solve.		Yes	

3 MAIN CONTRIBUTION

Our main contribution should be evaluated against existing solutions:

1. Paper exercises
2. Web questionnaires
3. Existing solutions for VSEPR study

Considering our own experience with the two first items and the validation results presented below on section 5, a few words should be said about the identified tutorial

Table 3: Examples of web pages with Chemistry games. PT stands for Periodic Table; CR stands for Chemical Reactions.

Game	URL	Description	Chemistry Level
Chemistry Games	http://www.sheppardsoftware.com/Elementsgames.htm	Learning mode: the user clicks over the symbol of an element and its main properties and characteristics are displayed; Gaming mode: questions about families, elements, symbols of the PT elements.	From elementary to advanced
Penalty Shootout Games	http://www.canaryzoo.com/Chemistry%20Games.htm	1. The user chooses a goal keeper. 2. A quiz appears. If the answer is right, the user may shootout a penalty and, if he has luck, it's goal. At the final of the game, there is a score of the number of right answers and the number of goals.	Elementary
Games for School Students	http://www.rsc.org/Education/SchoolStudents/games.asp	A set of games and tutorials that range from the PT through CR, oils, etc.	School level
Creative Chemistry	http://www.creative-chemistry.org.uk/	Set of applications covering elementary chemical chapters. Some time-attack questions, "impossible mission quizzes", and Chemical crosswords.	School level
General Chemistry Jeopardy Games	http://chemed.chem.pitt.edu/Jeopardy/genchem/index.htm	Jeopardy games covering several chapters of a Chemistry University level course.	University level
Chemistry Lab Escape	http://www.playonlineflashgame.com/2008/11/play-chemistry-lab-escape.html	The player is trapped on a chemistry lab and has to use the available clues to escape. The user doesn't need to have large Chemistry knowledge. It is more important to pay attention and be luck.	None

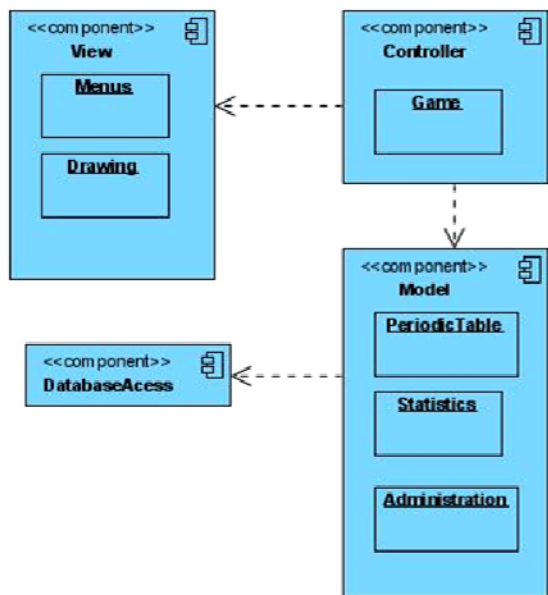


Figure 1: LeMo's component model through a model-view-controller architecture.

and quiz available at Virtual Chemistry (first row on

Table 1). Following a tutorial about VSEPR theory, the program shows one from a list of 20 molecules and the user has to select its molecular geometry from a list. In case it is correct, the application pops up a 3D representation of that molecule.

The present application (described below in section 4) is completely different:

1. LeMo is a game: it has levels, scores, lives, noises, other players, etc.
2. LeMo is more demanding in terms of Chemistry contents: it also includes the writing of Lewis formulas, the determination of the polarity of the molecules, the selection of the right angles between Chemical bounds, etc.
3. LeMo is a "student-friendly" application, as it points out the mistakes in real-time, with pop up messages whenever a mistake is made.
4. LeMo database is more complete. Presently includes 50 different molecules / molecular ions and the possibility of being extended is provided.

Actually, LeMo is a prototype of a new strategy for learning through gaming, which we intent to validate in order to continue the development of our own Virtual Laboratory.

4 LeMo

4.1 LeMo's Architecture

4.1.1 Component Model

LeMo's architecture may be described through the model architecture used to its development (Figure 1).

In the Model-View-Controller (MVC) architecture we have identified three, or four components, if we consider the database as separated from the Model component, which considering its relevance for the parameterization of the whole game, we need.

1. the "Model" package contains all the application data, which responds to requests for information about their status and responds to instructions to change state;
2. the "View" package which gives the Model classes a form suitable for interaction, for example, placing the atoms in the periodic table so that the user can interact with them;
3. The "Controller" package which receives data input from the user, such as clicking a button that initiates a response by making calls to objects of the package Model.

4. Finally, the database component comprises three main sets of information:

- a. information about registered users;
- b. the information about gaming and usage statistics and, finally,
- c. the information about the molecules and its structure that are available for gaming.

This used architecture already proved its robustness against changes in two ways: it took 4 person-hour to completely translate the initial Portuguese application used at EST Setúbal (<http://193.137.47.29/>) to the English version (<http://193.137.47.29/ingles/>) used in this paper and the inclusion of a back office is being straightforward, mainly due to the fact that it only interacts with the database.

4.1.2 Physical Architecture

The physical architecture is pure client-server (Figure 2), and the MVC component architecture may be directly mapped to it: the View, Model, Controller and database components are server residents. The View component is a Web Interface accessed by the client (user) computer through a web browser and running on top of a web server. The Model and Controller components are Java Applications running on the server.

4.1.3 Development Platform

The database used was created with mysql. The web interface is in php, so that users can alter their profile if needed or simply play the game in the page where it is called.

In selecting the technologies to be used, open source technologies were preferred, not only because they avoid unnecessary costs, but also because they were more familiar. Java was chosen as the programming language for the game application, as it is present in most operating systems used around the world, is used by both computers and mobile devices, its robust, it has a very active community, among other factors. In order to have the application on the Web, an applet was decided to be created.

The development environment picked was NetBeans IDE, as we consider IDE with a graphical environment pleasant and easy to use.

To develop the application site, php was chosen as language, as it is very powerful, very productive, easy to learn and well suited for the development of Web applications. Php is also easy to connect to the database, becoming ideal for this application. The

choice of mysql as the DBMS is due to its performance, and reliability.

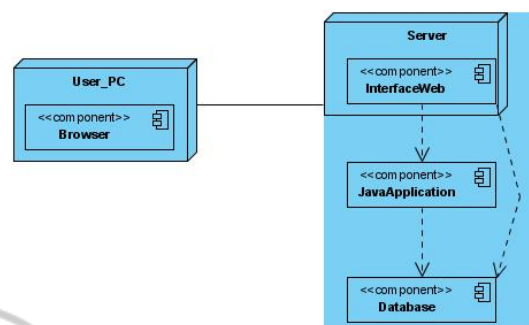


Figure 2: LeMo's Physical Architecture.

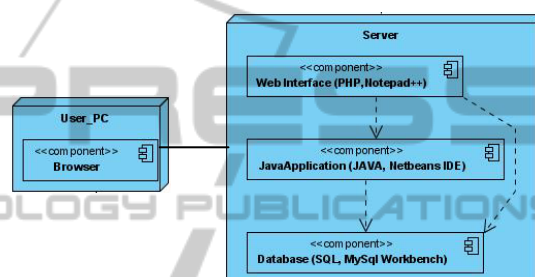


Figure 3: Development platform.

4.2 Playing LeMo

4.2.1 Access and Register

The first thing to do to experiment LeMo is going to <http://193.137.47.29/ingles/>.

1. If it is the user's first time, he should register.
2. After registration is complete, the user will be redirected to the contacts page where a welcome message appears and the player has access to his email address (in case there is any problem or the user wishes to give any suggestion).

4.2.2 Main Menu Options

Looking at the top menu on Figure 4 there are six options: "Game", "Personal Area", "Rules", "Statistics", "Contacts" and "Where we are?"

3. Selecting "Where we are?" the user's location will be presented in Google Maps.
4. If "Statistics" is selected, four tables of punctuation will appear: maximum, minimum, medium and stored. This tables show the top ten players in each category.
5. Selecting "Rules", the user has the possibility of watching 3 videos showing how to play. Each video

is a demonstration of each level of the game. Below the video, the objective of each level is described.

6. Selecting “Personal Area” the user has the possibility to change all his personal data, except the email address.

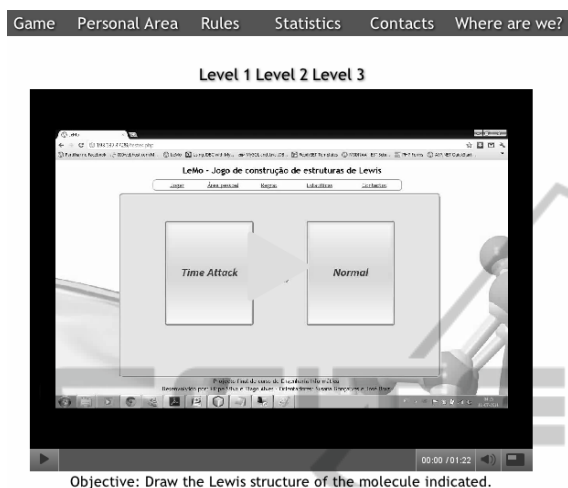


Figure 4: Rules page.

4.2.3 Playing the Game

Finally selecting “Game” the player will have access to game itself. When the game starts the player has to choose between two modes of gaming, normal or time attack (Figure 4).

The difference between them is that in time attack mode there is a clock running backwards that ends the game when the timer gets zero, sending an alarm sound. The game also ends when the number of lives equals to zero in both playing modes.

If the normal mode is selected the look of the game will be as presented in Figure 5.

At the first level the player is supposed to draw the Lewis formula of a given molecule or molecular ion. In the example illustrated in Figure 5 the chemical compound assign is CN^- . At the left side the user can find the total number of lives, the actual number and his score. At the top of the game area there is a periodic table and at the right side there are four buttons, with the three types of possible bounds to be formed between atoms (single, double and triple bounds) and a lone pair of electrons not shared (which is also a possibility for these formulas).

The player has to drag and drop the atoms from the periodic table and the bounds/not shared electron pairs form the connection buttons to the drawing area in order to draw the Lewis formula of the assigned molecule/molecular ion.

These elements can be rotated and deleted from

the drawing area by clicking with the right mouse button; the atom element can also be given a positive or negative formal charge using the same button.

If the structure to be drawn is a resonance hybrid (which means that has to be represented by several Lewis formulas, each one representing each contributing structure) the player has to choose the resonance hybrid option, above the drawing area and select how many contributing structures are necessary. Several extra drawing areas will be created, depending on the number of contributing structures. When the player finishes the Lewis formula representation, he clicks the confirm button.

If the Lewis formula is correct, score will be added to the score board and a congratulations message will appear, also asking whether the player wants to proceed to the next level or quit.

In case the structure is wrong, score will be removed from the score board, a life will be taken and a message mocking with the player and given tips about the possible mistakes he made will appear.

After the user succeeds in the first level and confirms the wish to continue, the second level layout appears. In this second level (Figure 6) the player has to attribute geometry to the molecule/molecular ion which Lewis formula he drawn in the previous level, using the VSEPR theory.

At the top of the game area there are two dropdown boxes that the player will use to select the correct combination of angle and geometry.

Whenever the player chooses a possible combination an animated 3D image of the geometry appears. Note that this only indicates that the combination is possible, not that it is correct.

After choosing the combination the player has to click in the confirm button. Then, like in the first level, in case the player has succeed, a congratulations message will appear, also asking whether the player wants to continue to the third and final level. Score will also be added to the score board. In case the player chosen a wrong geometry, score will be removed from the score board, a life will be taken and a message mocking with the player will be shown.

Once the player has completed the second level and confirmed he wants to continue, the third and last level layout is shown.

In this third level, as shown in Figure 7, the atoms are presented in the same locations the player has chosen at the first level (which may not correspond to their real locations, according to the VSEPR theory and the attributed geometry).

The player has to drag and drop the vectors to the

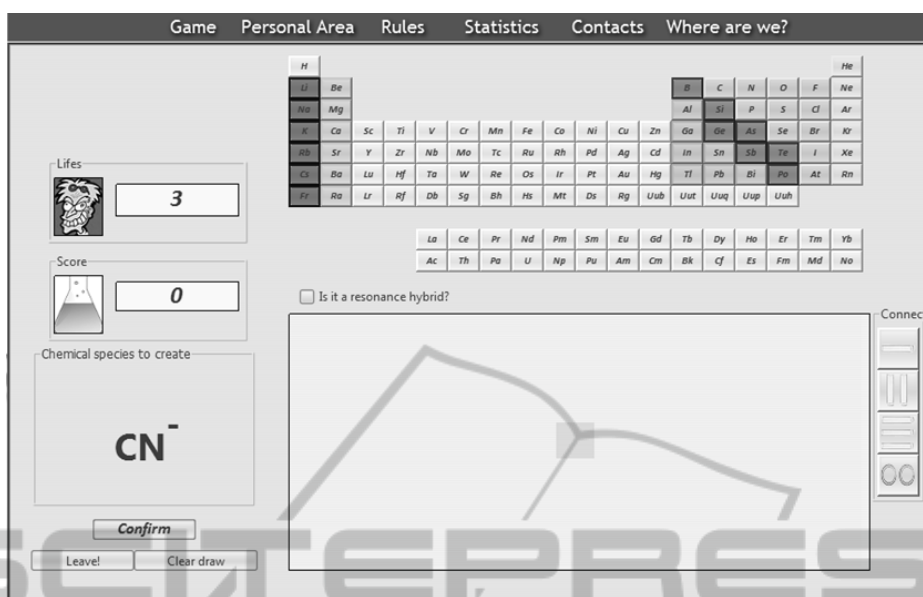


Figure 5: First level in normal mode.

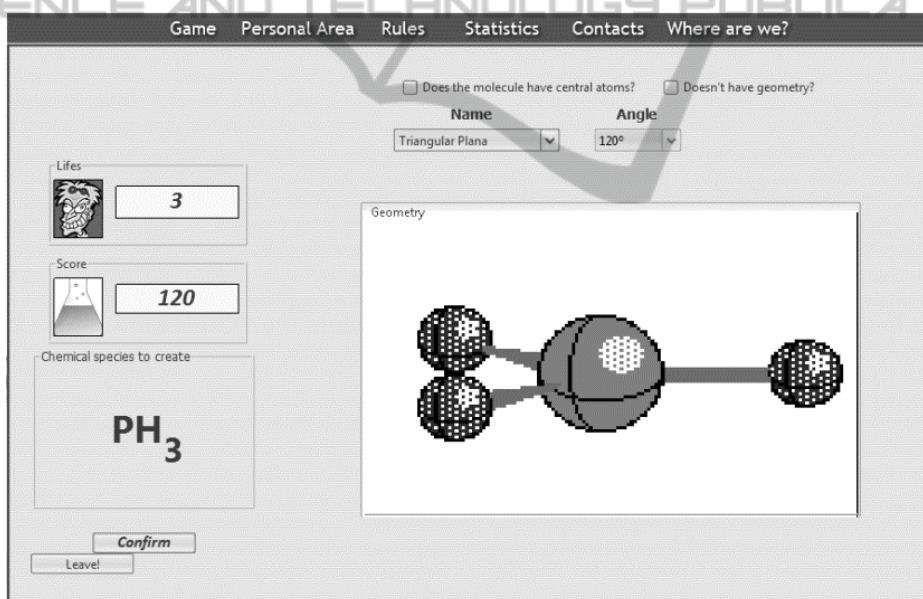


Figure 6: Second level in normal mode.

draw area in the right place and direction, and select the polarity of the structure in a dropdown box for that purpose.

If the player succeeds, the game is over. Score will be added to the score board and a congratulation message with his archived rank is shown at the sound of fireworks. At the same time the total score of the player is transferred to the database, to be used in the statistics of the game.

The player may then choose to play again in

order to get a higher score or to leave the game.

4.2.4 Funny Error Messages and Competition

All messages in this game have a type of language oriented to the students.

Since the main objective of the game is to be fun in order to increase the study duration and improve students memory in this topics, all messages have



Figure 7: Third level in normal mode.

also funny sounds and the game has music in background (that can, however, be turned off).

In order to increase competition between students and increase the time of study, the players may consult the high scores, accumulated scores, minimum scores and medium score charts.

5 VALIDATION

A group of 30 students attending the Chemistry course of the 1st year of Mechanical Engineering in EST Setúbal were divided into three test groups. During one week group #1 was only allowed to study by the exercise book, group #2 by the moodle interactive exercises and group #3 by LeMo. All these students were attending the Chemistry course for the first time. After one week, all students were submitted to a written test and an inquiry.

As seen in (Figure 8), 64% of the students using the exercise book found that method boring and 9% very boring. 67% of the students using moodle still found it boring, but as much as 33% answered that it was fun. In the test group #3, only 33% of the students classified it as boring. Indeed, 67% of the students said that studying by LeMo was a funny alternative.

The same figure also shows that 91% of the students using the exercise book considered it as a good method and 9% as very good. The opinions were more spread in the group of students that solved the moodle virtual exercises: 17% classified

the method as poor, 50% as good and 33% as very good. The majority of the students from group #3 (67%) considered LeMo a very good method for studying molecular structures and 33% good.

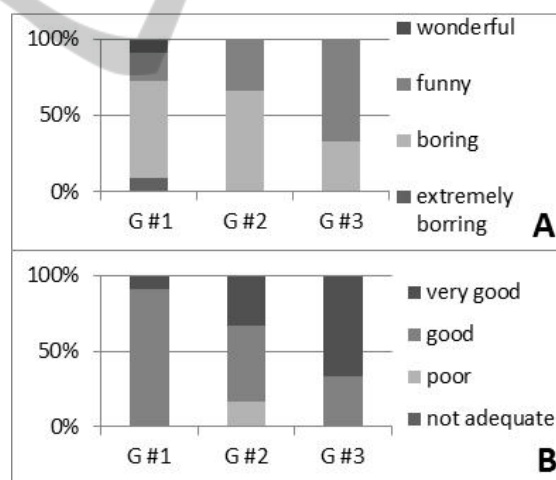


Figure 8: Answers of the students from each of the three groups to the same question "How do you classify the method you used to study this chapter?".

For 90% of the students in group #1, the major advantage of the exercise book is that they are used to it. For group #2, 67% of the students reported that the major advantage of solving the interactive exercises on moodle is the pop up tips that appear whenever students give wrong answers. Concerning LeMo, students were required to point out the three main advantages: 70% mentioned the real-time error

messages, 40% referred the competition with the colleagues and 40% stated the game was user-friendly. Note that moodle tips are much more generalist than the error messages of LeMo.

LeMo was well accepted by students, which identified and appreciated the fun character of the game and considered it a good tool for studying these matters.

Normal mode is preferred by 83% of the students, as it allows more time to think and to read the messages, while 17% prefer time-attack mode, saying that it is more challenging.

6 CONCLUSIONS AND FURTHER WORK

As said above, the aim of LeMo is to provide a new method for practicing the writing of Lewis formulas and applying VSEPR theory in a game format, in order to both motivate students not to give up and to help them memorizing images and concepts through emotions.

The developed application is absolutely new and, to our knowledge, completely different from all the others found in the cyberspace. It is more complete in terms of contents, has a larger database, is funnier than other applications dedicated to Chemical Structures, and is more adequate than other previous attempts made by the same group, as the moodle inquiries.

The evaluation of LeMo shows that a large majority of the students preferred to study using this new application. They considered LeMo a very good tool mainly because of the real-time pop up messages that point out their mistakes but also because they found it funny and challenging, which induces positive emotions. Are the latest contributing to their learning process? It is our opinion that further work is still required. Further validation tests are already planned to occur during the final exam of the Chemistry course for Mechanical Engineering students, with a larger test group (≈ 130 students) and with a new enquire (more directed to emotions).

As said, LeMo was developed as a permanent beta release, to be incrementally updated according to the users' feedbacks. Three tasks are already scheduled:

1. Development of a back-office allowing an easier introduction of new molecules in the database, replacing the current process (that involves tables) – this task is already in progress.

2. The full integration into the EST Setúbal e-learning platform, rather than the current link to the LeMo hosting site.

3. Development of an integrating environment, possibly using Virtual Reality, where LeMo will be one of the available applications.

Tasks number 2 and 3 are planned to start as soon as the second validation process is finished and gaming success unequivocally proven. They will mark the beginning of the ESTSetúbal Chemistry Virtual Gaming-Lab.

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