ChemCreator: A Game of Chemistry

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Abstract

The objective of this thesis is to create an educational chemistry game for high school students. With that objective in mind, this chemistry game needs to be entertaining and appealing to be played and thus other educational games were analysed in order to identify their strenghts and weaknesses. Furthermore, flow [3] and the experiental gaming model [3] were studied in order to make a connection between each other and as a result obtain a flow experience in the game. With the educational game analysis and these concepts studied, some guidelines were created with the objective to be followed when developing the game.
Keywords: Chemistry, Education, Guide, Implementation, Results

1. Introduction

Computer games have been growing in the past few years and have been seen differently by many generations. They are a way of entertainment and also knowledge for the users. As a consequence, educational games have also been growing and have the objective to help and teach the users about a large diversity of subjects such as chemistry, mathematics, science, music and much more. However, there is not a recipe for their success which is to be able to teach while at the same time the user is being entertained. The success of educational games can help both teachers and students in their quest to learn and can also change the traditional education method.

2. Background

This section explains the domain of the educational game that was developed. Furthermore concepts on how to make a good educational game will be explained and connected with each other in order to obtain some guidelines to follow in the game development. These guidelines will also be used when analysing some other good educational games with the objective to get their strenghts and weaknesses.

2.1. Domain

The domain present in the educational game that was developed can be divided into two main categories: Periodic Table and Bonds. Regarding the periodic table, it has a total of 118 elements with the elements 113 (Uut - Ununtrium), 115 (Uup - Ununpentium), 117 (Uus - Ununseptium) and 118 (Uuo - Ununoctium) yet to be discovered [14]. Besides having these elements, it has an organization in which the elements are organized through their own atomic number. Furthermore, the table is organized in periods (horizontal row) which can be seen in figure 1 and also in blocks which assigns a group to several elements such as alkali metals, metalloids, etc.

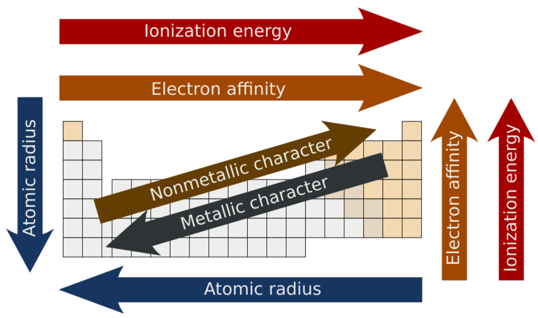

Figure 1: Periodic Table configuration, [14]

Each of the elements have a symbolic representation which gives four different types of information about an element: atomic number, mass number, respective representation and ionization state. For example, $^{24}_{12}Mg^{2+}$ represents the element Magnesium which has 24 mass number, 12 atomic number and the ionization state means that it has two more electrons than protons. The atomic number is equal to the number of protons in the atom and the mass number is equal to the sum of neutrons and protons of that atom.

Relatively to the bonds, only one subpart of its domain is present in the game which is the electronic configuration of atoms. The electronic configuration of an atom divides its electrons into seven shells and respective subshells [13]. Each shell and subshell have their max number of electrons and the outermost shell that has atleast one electron is called "valence shell". The way that shells are filled can be seen in the figure 2.

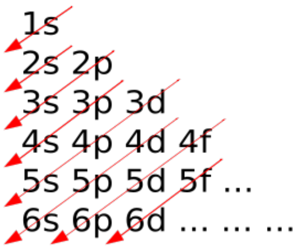

Figure 2: Aufbau Principle, [12]

2.2. How to make a good educational game

For an educational game to be good it needs to have accurate content that besides teaching it also demonstrantes and inspires its users. That said, fun and entertainment play a very important role in a good educational game. With this in mind, we can take advantage of most of the principles that make a game fun, appealing and entertaining by adding them on the game. Using powerful imagery, appealing audio, giving the user objectives, guidelines and competition, adapting and being interactive are some of the principles that help creating an entertaining and fun game.

In order to achieve these priciples, an educational game must have a flow experience. An activity that is performed in computer environments needs to be colapsed into a task and an artifact behavior in order to accomplish the flow experience [3]. The task is similar to a goal and the artifact corresponds to the tools that the user has to fulfill the task. Moreover, a proper flow experience is achieved when there is a balance between the skill and challenge that the game provides. The balance between skill and challenge can be seen in the figure 3.

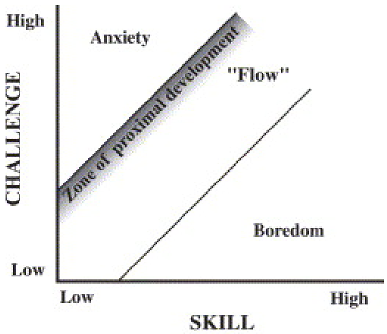

Figure 3: Skill and challenge balance, [3]

The work of Piaget, Lewin and Dewey [7] explains the concept of experiental learning and presents its respective model. For instance, this model has four stages. The first stage consists of a concrete experience which is succeeded by collecting all the data and reflections about this experience. Subsequently, in the third stage, the learner draws conclusions, makes generalizations and forms hypotheses. Finally, the learner goes on a cycle of active experimentation modifying the circumstances of each experimentation. This model gives feedback to the learner which leads to a goal-directed action.

The experiental learning model led to the creation of the experiental gaming model which has the objective to promote the flow experience in a game. This model describes learning as a cyclic process in which the user constructs cognitive structures through practicing and making actions in the game world [3]. This model consists of three cycles: the preinvative idea cycle, the idea generation cycle and finally the active experimentation cycle which can be seen on the figure 4.

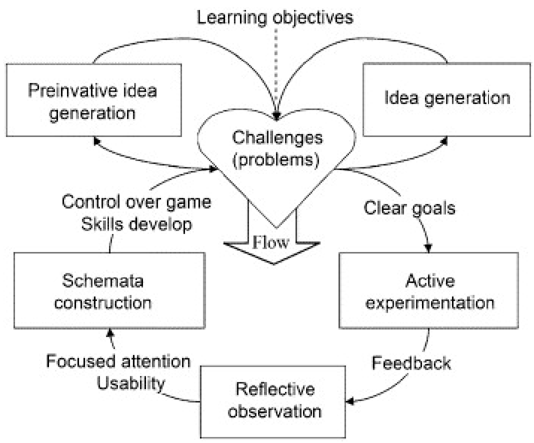

Figure 4: Experiental Gaming Model, [3]

On the preinvative idea generation cycle, the challenges originate from unstructured ideas that resemble the play of a children. On the other hand, the idea generation cycle challenges originate from ideas that take into consideration the constraints and available resources of the game world. These challenges lead to the last cycle in which the user starts trying to solve them. By doing that, the game should provide feedback for each of the user's actions in order to allow the user to reflect and form hypothesis and schemata which enable the discovery of new and better solutions to the problems.

Having into consideration all that was said before, a good educational game not only needs to have a flow experience but also entertain its users. To design an entertaining educational game, the first

concern is their content and then the playability layer is added on top of the content layer [4].
The concepts explained before can be correlated with the gaming diagram presented in the work of B. Paras and J. Bizzochi [9]:

Games → Play → Flow → Motivation → Learning

Games encourage playing which leads to a flow experience. The flow experience leads the user into a cycle of active experimentation which is present in the experiental gaming model. This active experimentation cycle makes the user generate several solutions, motivating him. If the game mechanics are well-designed then the user learns by reflecting and applying these solutions to reach his end goal and thus learning.
Finally, with the concepts previously explained and the addition of a master thesis [11] study, the guidelines to create a good educational game are divided into three main categories: entertainment, motivation and education. Each of this categories have subcategories, for instance, to have entertainment the game should provide challenges, social participation, story, good audiovisuals and creativity, to motivate the user, the game needs to be interactive, give feedback, have goals and give some support to the player and lastly, to educate the player, the game should have accurate content, be adaptive and have rules.

2.3. Game Analysis

Several educational games were analysed taking into consideration the guidelines defined in 2.2. Most of the games were related to chemistry however, "Numbers League" is related to mathematics. The results of the analysis are:

1. Spacechem [6]- all the guidelines previously described are present in the game.
2. Numbers League [8]- all the guidelines previously described are present in the game.
3. Toca Lab [2]- has nine out of twelve guidelines.
4. ChemGameTutor [5]- has seven out of twelve guidelines.
5. Science Kids [10]- has seven out of twelve guidelines.
6. Escape from chemistry laboratory [1]- has seven out of twelve guidelines.

Some more games were also analysed but they didn't have many guidelines and thus weren't taken too much importance for the development of the educational game. Yet, these six games have good strenghts and ideas which can lead to an entertaining and educational game.

3. Implementation

This chapter will focus on the implementation of ChemCreator. Furthermore, the conceptual and technical implementation will be explained and correlated to previous described concepts.

3.1. Conceptual implementation

The initial domain proposed by the school Dr. Azevedo Neves was too big for the pretended educational game. Instead of having three main categories on the domain, it was reduced to two: periodic table and bonds. Since covalent bonds can only occur to certain elements of the periodic table, it was opted to remove it and focus on the electronic configuration instead. To have a flow experience in the game, the first step was to remove gaps between the different parts of the domain. With this in mind, two different gamemodes were made and connected to each other and thus having similar game mechanics. In the two gamemodes, the user creates and configures atoms and thus the game name is a mixture of creator and chemical - ChemCreator.
The figure 5 shows all the concepts used to create both gamemodes and the connection between them.

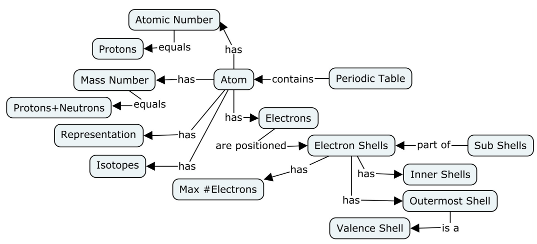

Figure 5: Conceptual map

Besides connecting each gamemode through the conceptual map, the flow experience was achieved by applying the experiental gaming model as explained in the section 2.2. The preinvative idea generation cycle corresponds to the first gamemode in which the user generates challenges by playing the game without any constraints with the objective to discover new atoms. This gamemode can be seen in the figure 6.

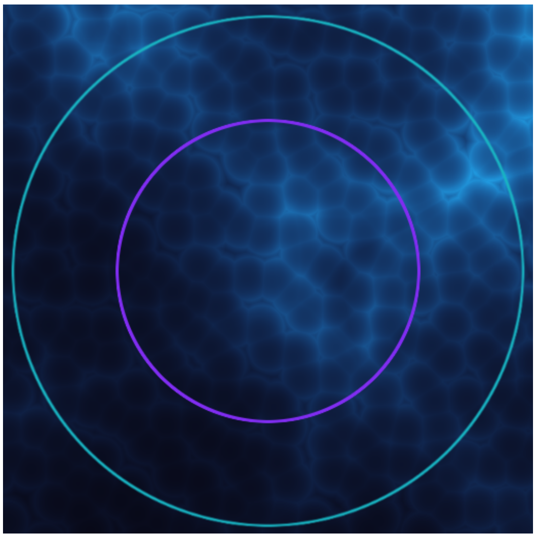

Figure 6: First gamemode

On the other hand, the second gamemode which can be seen in the figure 7 has constraints and resources that must be spent in order to generate challenges. Subsequently, this gamemode corresponds to the idea generation cycle in which the user takes into consideration the constraints of the game world. In the electronic configuration mode the user needs to configure the shells surrounding the atom and can only configure the atoms that were previously discovered in the first game mode.

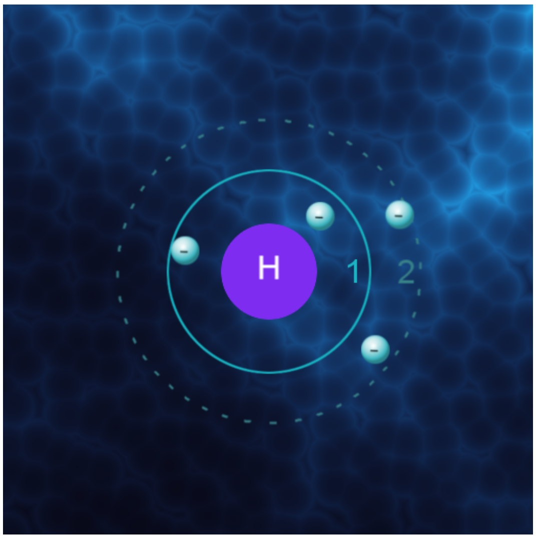

Figure 7: Second gamemode

Besides having these two gamemodes, the first gamemode provides an option to add constraints to the discovery of atoms because the user can go to the periodic table and click an undiscovered atom in order to discover it. By doing that, the chosen atom will have only the correct neutrons and the user only needs to discover the corresponding number of electrons and protons.
These two idea generation cycles lead to the third cycle of the experiental gaming model in which the user has clear goals - progressing through the periodic table, unlocking achievements and configure electronically the atoms. By solving these goals, the application will give its respective feedback to the user and thus he can generate hypothesis and schemata and thus discover and create better solutions for his problems.
All the design of the game is very simplistic in order to provide clear answers to the user. However, it is also appealing and motivates the user.

3.2. Technical implementation

The development of ChemCreator consisted on five main development iterations.
The first iteration focused on the movement of neutrons, protons and electrons, user interation with these elements and also the creation of atoms. The initial user interation with the elements was not very user-friendly since the elements had a movement similar to a spring when getting dragged. Consequently, the movement changed into a simple drag and snap.
The next iteration focused on four topics: cookies to save progress, feedback when a new achievement is earned, a minimalistic mode - way to reduce the number of electrons, neutrons and protons on the screen - and some tweaks on the dragging of elements.
ChemCreator's initial visual representation of the periodic table was started in the third iteration. Furthermore, this iteration included the development of the different electron shells around the nucleus of the atom and thus the electronic configuration mode.
On the fourth iteration, an error was discovered regarding the way that shells were being filled with electrons. Consequently, it had to be fixed and a new way to view the shells had to be created. Instead of having only two ways for a shell to be viewed - circular dashed line or circular full line - there is a new one which represents a full subshell - red circular dashed line. Besides fixing this error, the game got divided into two gamemodes. The first gamemode allowed the creation of atoms and the second one, which was accessible through the periodic table, allowed to configure an atom electronically.
Finally, the last iteration focused on four topics. Firstly, the periodic table and respective database of elements was completely done and filled. Its final visual was finished aswell and can be seen in the figure 8.

Figure 8: Periodic Table in ChemCreator

Secondly, the electron configuration mode was completed by adding the sub shells text on the top left corner in order to give more feedback to the user. Thirdly, another way of progressing through the game was added - achievements. Lastly, since the game needed to be tested with users, besides having the progress saved on cookies, a database had to be created in order to be able to retrieve some more data and also provide another option for students that share the computers in their respective school and will only play the game there.

3.3. Sofware

The software used in the development of the game was:

1. Gimp - edition of game visuals.
2. JavaScript - main coding language of development.
3. Phaser.js - game framework of JavaScript.
4. JQuery.js - JavaScript library that has many built functions to help on the game development.
5. JQuery cookie plugin - Plugin of JQuery that helps dealing with cookies.
6. MySQL, Ajax, Json and Php - languages used for the creation of the database and share of data.
7. Brackets - Code editor.
8. PuTTY and WinSCP - SSH clients.

4. Results

To be able to identify if ChemCreator was fulfilling its educational purpose and at the same time entertaining, user testing had to be done. Furthermore, this user testing consisted of moderated tests, unmoderated tests and two different questionnaires. The reasons for choosing these methods of testing will be presented on the next sections. There were a total of twenty five students in the tests, all of them from the tenth grade. Fifty six percent of the students are male and the rest is female and all have around sixteen to seventeen years old. Some students were repeating the tenth grade for the first or second time.

4.1. Problem Description

ChemCreator has the objective to teach chemistry on a different way that schools do. For this reason, there are several problems. Firstly, the content of the game must be accurate and equal to the one taught on schools. Secondly, playing ChemCreator needs to be more appealing to play than directly studying chemistry. The last problem that ChemCreator tries to solve is to aid the teachers by explaining chemistry through ChemCreator.

4.2. Baseline Solution

For the baseline solution, ChemCreator needs to have accurate content, be more appealing than the normal way to study and aid teachers to explain chemistry.

4.3. Enhanced Solution

The optimal solution includes the baseline solution and also replaces the normal way to lecture chemistry. This means that ChemCreator will lead teachers to a more efficient way of teaching Chemistry.

4.4. User Testing

In order to guarantee that a decent amount of data was produced to be analysed, two different types of user testing had to be done. These tests not only produced data to the database of ChemCreator but were also used to fill the questionnaires. The moderated tests happend twice since they had to be done after and before filling the chemistry questionnaires. On the other hand, the unmoderated tests only happend during one week.
Regarding the moderated tests, they consisted on a showcase of the game for about four minutes each of the times. These tests were done due to the fact that there was no guarantee that the students would play the game when not being watched. Furthermore, the unmoderated tests corresponded to a period of a week in which several students offered to play ChemCreator. These two types of tests would guarantee that we would have enough reliable data to analyse on the questionnaires.

4.5. Questionnaires

Two types of questionnaires were done to the students. The chemistry questionnaire, which focused on knowing the chemistry knowledge of the students, happend twice and was divided into the students that offered to play ChemCreator and the students that didn't offer to play ChemCreator, in order to make a distinction of results for the students that played the game for longer periods of time. The students that didn't offer to play the game had only around 21% of correct answers as can be seen in the figure 7 and the students that offered to play the game had around 27% of correct answers.

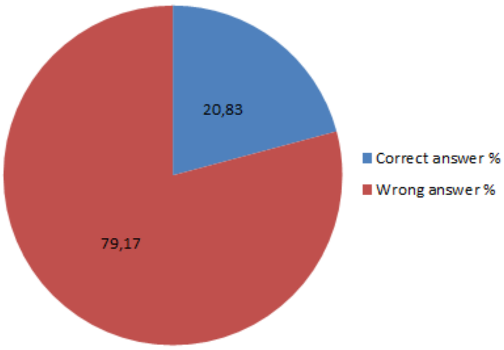

Figure 9: Percentage of correct and wrong answers before the game showcase by the students that didnt play it

One week after these chemistry questionnaires, ChemCreator was showcased for four minutes - moderated tests - and the same chemistry questionnaire was made to the same students. The percentage of correct answers for both groups of students changed. Moreover, the percentage of correct answers by the students that didn't offer to play the game rose from 21% to 80% as can be seen in the figure 10 and the percentage of correct answers by the students that played ChemCreator in a period of one week rose from 27% to 77%.

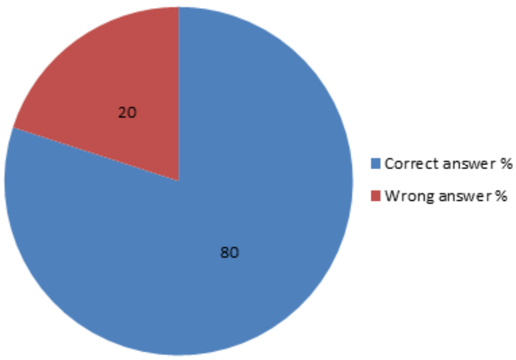

Figure 10: Percentage of correct and wrong answers after the game showcase by the students that didnt play it

However, unexpected results happend between the two groups of students. The students that played ChemCreator had a 50% increase on the correct answers and the students that didn't play the game had a 59% increase. This increase of correct answers should have been exactly the opposite - the students that played the game should have increased more when compared with the students that didn't play the game. Yet, the database of ChemCreator shows that only three out of five students that offered to play ChemCreator, actually played it. Also, these three students only played ChemCreator once. Moreover, three out of the five questionnaires filled by the students that played ChemCreator had 100% correct answers which might correlate to the students that actually played the game. Both group of students had a big increase on correct answers in a very small amount of time, which might be a good indication that ChemCreator main objective is achieved.

Besides this chemistry questionnaire, a questionnaire about ChemCreator utility and users game habits was done. With this questionnaire several conclusions were obtained. Firstly, only one fifth out of the twenty five students have the main platform to play ChemCreator - the computer. This might be concerning but schools normally have libraries which have computers and thus fixing this problem. Secondly, fifty six percent of the students have already played educational games but only fifty percent of these students continue playing educational games. Thirdly, sixty percent of the students prefer to play ChemCreator over studying as can be seen in the figure 11. This percentage can be increased by increasing ChemCreator's game visibility - more students playing it and teachers using the game to teach chemistry.

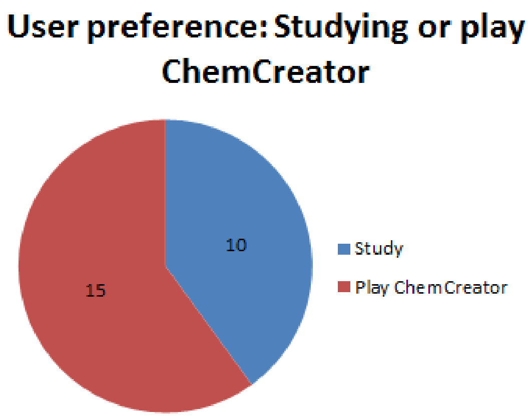

Figure 11: Question # 7

Besides prefering to play ChemCreator, seventeen out of twenty five students said that they had fun playing the game and that they abstracted themselves from being playing an educational game. Finally, ChemCreator had an average classification of 7,5 out of 10 which is a good result specially because ChemCreator still doesn't have much visibility in the community.

4.6. Questionnaire to a chemistry teacher

With the objective to have a different point of view on the educational purpose of the game, a questionnaire to a chemistry teacher was also done. This questionnaire happend before the teacher had seen ChemCreator's showcase and also played it at home. This questionnaire consisted of the following six questions and respective answers:

Does the professor think that the game helps teaching chemistry in a more fun way? Answer: I think that the game is a very good strategy to teach the atomic structure, the concepts of mass number and atomic number and the electronic configuration of an atom in an appealing way, allowing it to be competitive and fun.

Does ChemCreator replaces the normal way of teaching chemistry? Or is it more of a support to teaching? Answer: The game can replace the traditional way of teaching since it allows the rediscovery and simulation of concepts, models and principles involved.

Do you think that students prefer to play ChemCreator and thus learn passively or learn chemistry in the classroom? Answer: I think that the students prefer to play, it attracts their attention and learn by themselves.

Do you think that by using ChemCreator to teach chemistry, you will captivate more the students attention? Answer: I think that it captivates more. That way they can predict and verify if their ideas are correct.

Does the game work as a way of remembering chemistry? Answer: It also works as a way of remembering chemistry. In a few minutes they can remember what they learned.

Does ChemCreator help teaching chemistry? If yes, why? Answer: It helps on teaching since it is an appealing application which allows the study of multiple options, and thus compare different situations, formulate hipothesis and test them... in the end, experiment them.

By analysing the answers of the questionnaire, ChemCreator can be used not only by the students but by the teachers in order to help them teach Chemistry. ChemCreator helps remembering and can teach chemistry in a very appealing, fun and captivating way.

5. Conclusions

At the start, the domain of the game seemed smaller than it really is. As a result, different gamemodes are needed to achieve the pretended game otherwise the user experience won't be good and therefore the game won't have success. As a consequence of this big domain, it was opted to reduce it into two subdomains: Periodic Table and Electronic Configuration.

After analyzing different games some of them are featured for their qualities. These games met most of the users needs and were followed when developing ChemCreator.

ChemCreator consisted of five development iterations. These iterations tried to follow all the guidelines presented. One of the most important qualities of an educational game is its flow experience which was achieved in ChemCreator through the experiental gaming model.

In the development of ChemCreator, there were some challenges and difficulties. The lack of experience in coding in JavaScript was the first difficulty since there was no subject throughout all my studies that required this coding language and thus there no contact with this language before. JavaScript has a completely different programming paradigm when compared to the most usual languages and at the start it was a bit difficult to start coding the game. Besides this difficulty, choosing the correct physics engine to use in ChemCreator was also tough since one "object" can only use one type of physics. Each physics engine had their own restrictions and thus was hard to choose the correct one that would do everything pretended. Although, the hardest part of the development occured in the creation of an algorithm to correctly fill the shells and subshells of an atom through the Aufbau Principle [12] since shells aren't filled linearly. Besides this, all the elements of the periodic table were filled by hand which also took quite a long time. To make this process faster, an HTML parser should have been done and that way it would get only the needed information of the websites and then automatically fill the database with the correct elements of the periodic table and respective isotopes.

The results obtained were very good for several reasons. Firstly, the students learned chemistry in a very low period of time. Secondly, ChemCreator can be used by teachers to help them teach chemistry and thus ChemCreator has another audience that can play the game. Finally, ChemCreator can be used as a way of learning or remembering chemistry.

The most important achievement present in this work is the creation of a functional educational game which highly increases the students perception of chemistry and helps them on learning chemistry. Besides this achievement, it can be prooved that the experiental gaming model and the flow's artifact-task behavior are connected and can be present in an educational game.
Regarding the future work, there are many different game modes that can be implemented on ChemCreator in order to teach other parts of chemistry domain. Also, more appealing visuals for all the application can also be made. Besides this, sound might also be a way to make ChemCreator even more appealing and thus can also be done.
To conclude, ChemCreator might be an important step forward on helping the students study and learn chemistry.

6. Acknowledgements

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