




An Auto Battler Game to Engage High School Student's Understanding of Ionic Bonds in Chemistry

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Abstract. This paper describes the development and evaluation of a serious game to help high school students understand the topic of ionic bonds in chemistry. Chemistry is among the lowest-scoring subjects for high school students due to complex chemistry concepts and syntax difficulties. The novelty of this study is a developed auto battler game that includes specific learning objectives regarding ionic bonds. 27 Danish high school students participated in the evaluation. The evaluation consisted of a knowledge test and a questionnaire with items from the user engagement scale. The findings revealed that the high school students were positively engaged in the battle game. The grand mean for eight engagement items, based on a 5-point Likert scale, was 3.78. Specifically, the participants perceived the graphics and visual elements as highly positive. Further, they were concentrated while playing and were interested in the game. The students provided positive statements in the open-ended comments, including a good, creative, cozy, well-made, engaging, and fun game. However, the learning outcomes were not as satisfactory as expected. In the paper, we outline reflections on difficulties when measuring learning outcomes in game-based learning.

Keywords: Game-based learning · serious games · game development · auto battler game · chemistry · learning game

1 Introduction

This study explores the potential of using serious games to enhance high school student's understanding of ionic bonds in chemistry. Many high school students struggle to learn chemistry concepts [1, 2], including ionic bonds, as part of the mandatory curriculum. Chemistry is among the lowest-scoring subjects for Danish high school students [3]. The reasons for these are complex chemistry concepts, syntax difficulties (chemical formulas), and misunderstandings of the connections between models, symbols, and microscopic levels [4, 5]. Given these difficulties, various educational games have been

created to supplement learning in chemistry and capitalize on games' ability to captivate students and stimulate their engagement [1, 2, 4–7]. The novelty in this study is the design of an auto-battle game intended to engage students and enhance their understanding of ionic bonds. An auto battler is a subgenre of strategy video games where players place characters or objects on a battlefield during a preparation phase and then fight an opposing team without further input from the player. Educational battle games are already used, with many variations [8, 9]. Still, they have the common foundation of a composed team that, with various selected objects, commodities, strengths, or personalities, battles other teams. The result of the battle is most often a win or loss. However, to our knowledge, no studies have supplemented high school students' understanding of ionic bonds using an auto-battle game. This study was based on the following research question:

RQ: How can an educational auto battler game be designed to enhance students' understanding of ionic bonds?

To answer the research question, the following learning objectives (LO) were established in close collaboration with a high school chemistry teacher. The learning objectives provided prioritizing and focus areas for the game. Further, one success criterion (SC) was established within the game engagement.

LO 1: Understand ionic bonds are formed by combining a cation and an anion.

LO 2: Understand that ionic bonds have no electrical charge.

LO 3: Understand that ionic bonds are chemical salts.

LO 4: Can name five different ionic bonds by their chemical name while looking at a list of elements from the game.

SC 1: The grand mean should be above 3.41, based on items within engagement items, using a 5-point Likert scale.

A common problem for educational games is to measure the learning effects [10, 11], but one approach is to target specific learning objectives and evaluate these in a knowledge test [12, 13]. However, a serious game (including a knowledge test for evaluation) is often insufficient for measuring deep learning [11]. This is why we have based LO 1 to 4 on the lower domain levels (remembering and understanding), following Bloom's taxonomy of hierarchical models used to classify educational learning objectives [14]. The included engagement measure (SC 1) is inspired by other studies [2, 13] within the use of the User Engagement Scale Short Form (UES-SF) [15]. The threshold for being above 3.41.

2 Previous Research

Existing research has explored various applications of educational games in chemistry across various game genres [1, 2, 4, 7, 16–20]. Subject examples include naming chemical compounds, organic chemistry, and redox reactions. However, there is a notable gap in the literature around utilizing severe games to teach the theoretical foundations of ionic bonds. Games can be used as an alternative teaching method, utilizing learners' adaptability to cater to their cognitive levels and interests through gaming as a medium [11], and has been found to increase the learner's engagement when compared to traditional learning methods [2, 11, 13, 19, 20]. Further, games have, through their interactive,

rule-based, and adaptive guiding, the possibility of affecting the players' motivation to learn chemistry [20]. Several studies have emphasized that educational games can be an excellent approach to teaching chemistry and potentially be more effective for cognition, retention, and motivation than traditional teaching [20–23].

The novelty effect when including games in an educational context is often very difficult to control and measure. Further, it can be challenging to measure the learning effect size [11, 24]. However, it is well known how engagement can be used as an indirect learning indicator [11, 13, 24, 25]. Yet, game engagement is challenging to define and measure, as it is associated with various other concepts, such as flow, immersion, motivation, and enjoyment [26]. Previous research for measuring game engagement has included approaches from user engagement perspectives [15], qualitative card sorting perspectives [26], and various questionnaires such as the E-flow [27] or the Game Engagement Questionnaire [28].

Previous research on educational battle games has reported easy engagement in the games [8, 9], even without any real-world reward. This aligns with other reported elements on motivation in serious games [11], that intrinsic motivation is essential, and that games for educational purposes could focus more on intrinsic motivation [30].

3 Methods

3.1 Participants

The study included 27 high school students (18 females, 9 males). The participants were from two chemistry classes. 26 participants were taught chemistry at the B level (medium level), while one was taught at the A level (Upper level). The high school is in the Copenhagen suburbs and has around 1000 students enrolled. A teacher in chemistry from the high school was included in the game design process as part of a co-creation, including knowledge about the subject and access to the students.

All participants gave informed consent and were told they could withdraw from the study at any time and that their participation did not influence their grades. In addition, all participants were provided with anonymous ID numbers, and all data were labeled with these IDs. We applied special considerations when recruiting teenagers (ages 16–18) following Danish data law, the international code of conduct, and ethical approval from the high school.

3.2 Procedure and Data Analysis

Each participant was randomly assigned to one of four test stations. Each station had a test conductor assigned. A test leader oversaw the test conductors to ensure the correct procedure and escorted participants to and from the classrooms. Thirty minutes were allocated for each group of participants, meaning it was possible to perform the test with eight students per hour. A test station consisted of a computer with a chemistry game and digital access to questionnaires, including a knowledge test and items with inspiration from the User Engagement Scale Short Form (UES-SF) [15]. The knowledge test consisted of four questions corresponding to the four learning objectives. The first three

questions in the knowledge test were multiple choice, with four possible answers for each question. The last question was open-ended. After the UES-SF items, the participants were encouraged to comment on the game in an open-ended text box. The UES-SF was analyzed by mean and standard deviation, and the open-ended question was coded into positive or negative statements. The knowledge was analyzed by cumulative frequency.

4 Design and Implementation

4.1 System Design

The game is a 2D auto battler game, played on PC, using only the mouse for interaction. The interface consists of GUI elements like text, images, and buttons. The game is inspired by Super Auto Pets [29], using similar phases and mechanics. The game’s goal is to build a team and have it survive against opponent teams. A team consists of ions or salts, collectively called “units” in the game. Figure 1 outlines the system design. The player goes from the menu (start game) into the setup phase (Fig. 1). In the setup phase, the player should compose their team, buy new units (ions), sell units, refresh (reroll) in the shop with coins to get new units, and read a handbook of helpful knowledge about ionic bonds. When the students are ready (finalize what they perceive as a strong team of units with their selected and formed ionic bonds to defeat other teams), they click on “Start Battle.”

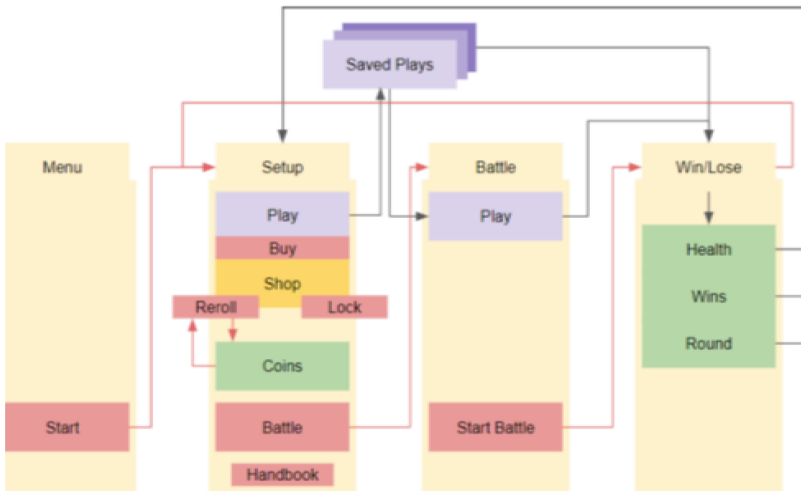


Fig. 1. The system design of the auto battler game

The player then enters the battle phase, in which their team and a randomly selected opponent’s team (based on the player’s stats from the pool of saved plays) battle each other. The battle winner gains a “win,” whereas the loser loses one “health.” The player returns to the setup to create new units. This loop continues until the player has won or lost five times, after which they return to the menu.

4.2 Set-up

The setup features a shop where units can be purchased. In addition, player stats are displayed at the top of the screen (Fig. 2). The player stats are metrics of how well the player is performing. It consists of a heart, a counter, and a trophy. The heart indicates the player's health. If the player has no hearts left, they lose the game. The counter shows how many rounds the player has played. The trophy represents how many rounds the player has won. The player stats are changed according to the battles.



Fig. 2. The player sets up a team. Player stats (top), the shop (lower left), and the team.

The shop is automatically filled with units when the player enters the setup environment. The player can buy them by placing them on the team. The game includes a subset of units from the periodic table. In the game, units are the entities that make up a team. A unit shares properties with the element that it represents. This includes information such as charge (e.g., $1-$, $2+$), chemical name (e.g., magnesium, sodium chloride), and type (atom, ion, salt). The unit's strength is based on the element's number of electrons. A unit can also damage the stats based on the element's number of electrons. The health stat is based on the element's atomic weight. The stats are always displayed below the unit (Fig. 3).

The player can buy and sell units. The costs (and sell profit) depend on the number of ions in the compound (Fig. 4). If the player is not satisfied with the selection in the shop, they can roll to have new units (Fig. 4).

Units placed on the team can be rearranged, combined, or sold. Rearrangement is done by selecting the units in question. Both combined units and non-combined units can be on the team. The ion must be on the team to be combined with another ion. The



Fig. 3. Units' damage and health stats are displayed in the game.

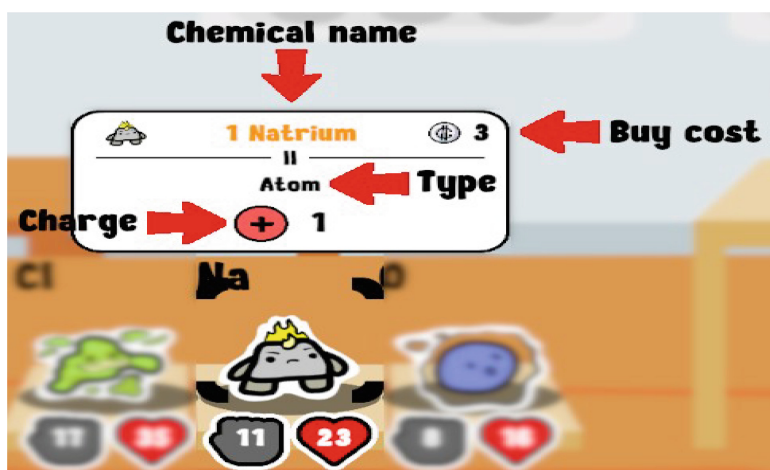


Fig. 4. The costs depend on the number of ions in the compound.

order of units on the team is not arbitrary since the slots have indices associated with them (Fig. 5). During the battle, the unit furthest to the right engages first.

4.3 Battle Win/Lose

The player stats are changed because of the battles. The setup features a shop where units can be purchased. In addition, player stats are displayed at the top of the battle begins when the player presses the fight button. Once the battle begins, both teams' front unit will fight (Fig. 6). Fighting consists of the two front-most units subtracting their damage from the opponent's health (Fig. 6). Once a unit's health is zero or less, it is removed from battle, and the next unit in line takes place.

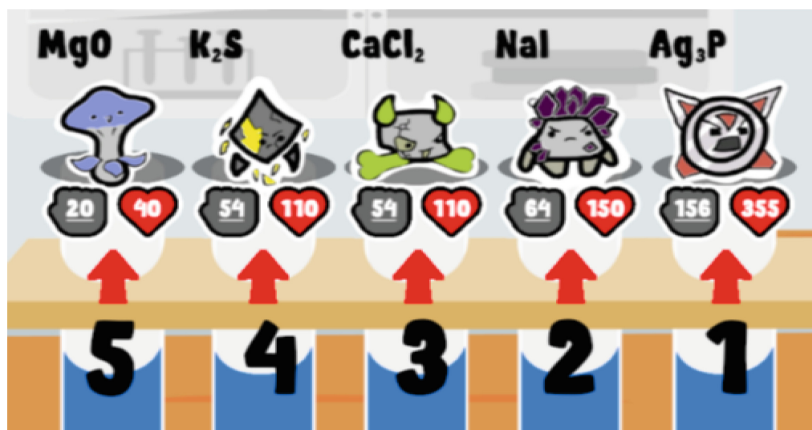


Fig. 5. The order in which the units on the team will fight an opponent team.

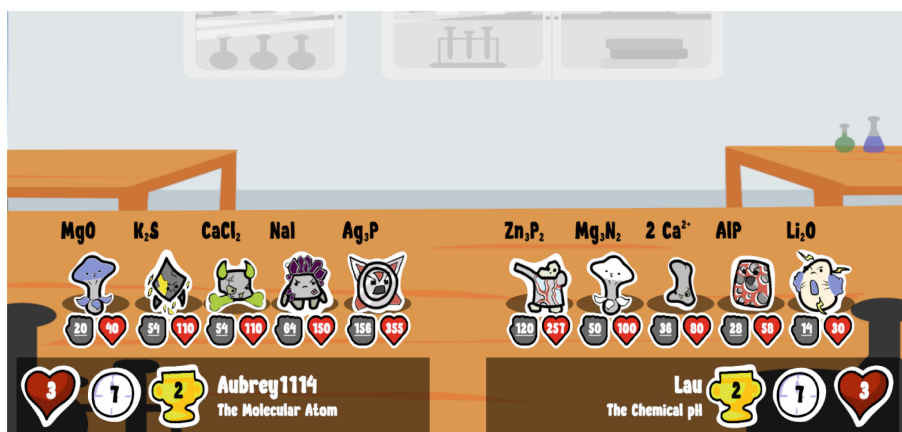


Fig. 6. The battle. The player (right side) battles against the opposing (auto) team.

The team left standing is the victor. If the player wins the battle, their wins stat is incremented, and if they lose, their hearts stat is decremented. The battle can end in a draw, where the player's hearts and wins stats are unchanged. Regardless of the battle outcome, the rounds stat is increased.

5 Findings

5.1 Engagement

Based on the engagement questionnaire (Table 1), the findings reveal that the participants were engaged with a grand mean score of 3.78. The items that yielded the highest mean score were in I5 (I like the graphics in the game, $M = 4.19$) and in I4 (The visual elements

were easy to understand, $M = 4.11$). 18 of the participants either agreed or strongly agreed in I6 (The game was fun, $M = 3.85$). The lowest mean scores were yielded in I7 (The game was worthwhile playing, $M = 3.41$), and in I3 (I was absorbed while playing, $M = 3.44$). Based on the engagement scores, the game was very successful. Interestingly, the graphics and visual elements items scored above 4. For the I5 item, the original item uses the wording - “This was aesthetically appealing” [15]. However, to have high school students understand the wording, “the aesthetically appealing” was changed to “I like the graphics.” In video games, graphics are commonly used and refer to visual elements and images displayed in the games.

Table 1. Engagement in the game. $n = 27$

Item/ 1 = Strongly disagree. 2 = Disagree. 3 = Neutral. 4 = Agree. 5 = Strongly agree	1	2	3	4	5	SD	Mean
I1: I was concentrated while playing	0	1	10	10	6	0.847	3.78
I2: The time I spent playing just slipped away	0	3	6	13	5	0.903	3.74
I3: I was absorbed while playing	0	8	4	10	5	1.121	3.44
I4: The visual elements were easy to understand	0	1	3	15	8	0.751	4.11
I5: I like the graphics in the game	0	1	1	17	8	0.681	4.19
I6: The game was fun	0	1	8	12	6	0.818	3.85
I7: The game was worthwhile timewise	1	2	13	7	4	0.971	3.41
I8: I felt interested in this game	0	3	6	13	5	0.903	3.74
Grand mean							3.78

Notable, most of the participants were concentrated while playing (I1, $M = 3.78$), felt that the time slipped away (I2, $M = 3.74$), and were interested in the game (I8, $M = 3.74$). The I6 “The game was fun” was with the third highest score ($M = 3.85$) and should be understood in the same way as other scholars have outlined this complex aspect of fun as a level of enjoyability [31]. The fun or level of enjoyability is also mentioned quite often in the open-ended questionnaire (Table 2).

Other positive comments (Table 2) include a good, creative, cozy, well-made, engaging, and fun game. There are also examples of students finding the game too difficult

(R4, R7) due to their perceived lack of chemistry knowledge. Some students also mention that the game could be improved by making it an online game with battles between classmates or friends instead of an auto battler (R4).

Table 2. Comments in the open-ended questionnaire. R = Respondent ID

Positive comments	Negative comments
It was a good, interesting game and a good educational game (R0)	The game could be improved by better graphics and intro (R6)
It is a creative and well-designed game (R1)	It would be easier if you could see whom you are fighting against and then return to the setup menu to be more prepared for the battle. Another idea is to create it as an online game so you can play against your classmates or friends. This would make it fun and competitive, like Kahoot (R4)
Well-made game. It draws you in (R3)	The game is challenging (R4, R7)
It was a good game. I want to play again (R5)	The evil ionic bonds are very powerful, especially in the beginning (R4)
Very cozy game (R1, R6)	
The game was fun (R4, R7)	
Good game (R0, R2, R3)	

5.2 Knowledge Test

As it appears from Table 3, there were some difficulties with most of the learning objectives.

The highest number of correct answers was in Q3, with 59% correct answers. The second highest number of correct answers was in Q1, with 52% correct answers. For Q3 and Q4, the number of incorrect answers was higher than the number of correct answers, especially for Q4 (open-ended), with only 19% correct answers. It must be emphasized that the questions were rather tricky (for chemistry level B). To provide the correct answers, the students needed to synthesize learnings from the game, meaning that the answers were not directly mentioned in the game.

6 Discussion and Limitations

Despite the high engagement score, is this auto battler game a failed attempt for a serious game due to the relatively low scores in the knowledge test? The answer to this discussion question is rather complex. It is hard to design a good game and very hard to design an excellent educational game, so making a good game, which is also

Table 3. Findings from the knowledge test. n = 27

Learning objective (LO)	Question asked (Q)	No correct	No. Incorrect	% Correct
LO1: Understand that ionic bonds are formed by combining a cation and an anion	Q1: What charge does an ionic bond have?	14	13	52
LO2: Understand that ionic bonds have no electrical charge	Q2: What happens when positively and negatively charged ions meet in an ionic bond?	10	17	37
LO3: Understand that ionic bonds are chemical salts	Q3: What bond forms a cation and an anion?	16	11	59
LO4: Five different ionic bonds can be named by their chemical name	Q4: With help from the periodic table, can you name at least five different ionic compounds? (open-ended)	5	22	19

suitable as an educational learning game, is ten times harder. The problem can often be in the design process and the team of game designers. Usually, the game designers focus primarily on the game side and do not know the student's learning skills or progression. Therefore, it is a considerable advantage to frequently involve the teacher in the game design process as part of the co-creation, including knowledge about the subject and access to the students. However, the teacher is the expert in teaching and learning but might not know the boundaries for a good game design. Potentially, because of this, lots of serious games for educational purposes are often seen as made too difficult in terms of the specific learning content, as revealed in this study.

An explanation for the unsatisfactory result from the knowledge test in this study could be a lack of a clear link between the learning objectives, the game design, and the evaluation. The students in this study sample were at the chemistry B-level (medium level) and should be able to answer the questions. However, in some evaluation questions, the students misunderstood and misinterpreted the questions and answered incorrectly. Further, the learning objectives were not very clear in the game. Another challenge was the time limit for the participants due to the class's duration.

The existing literature [32–34] includes various examples of how to evaluate serious games. However, when conducting evaluations in specific contexts with real users, in this case, with high school students at the high school, it isn't easy to conduct a perfect research evaluation. Logistics, time constraints, gatekeepers, legislation, lack of a proper posttest, technical issues, and lack of resources can hinder evaluations. Game evaluation with teens is complex, but further questions should be raised about how we evaluate serious games with children and teenagers. A significant limitation of this study is whether the teens understood the questions asked and could cope cognitively with the

instructions in the game, the specific chemistry content, the phrased knowledge test questions, and the 5-point Likert engagement scale. In addition, randomization is often impractical for evaluating serious games in a fieldwork context. It could also be unethical to randomize students in the same class, with some playing the game and some not; this setup should also be avoided because of the potential learning effects.

In future iterations, the game should provide a better one-to-one connection between the learning objectives and its content. This could also be included with additional repetition elements. Further, the tutorial needs to be shorter and more precise. More structured collaboration with the chemistry teacher, comprehensive risk management, and more pilot testing would have mitigated these low scores in the learning objectives.

7 Conclusion

This study intended to develop an engaging educational game to enhance high school student's understanding of ionic bonds. The designed auto battler game was perceived as positively engaging. From the engagement questionnaire, it can be revealed that the visual elements and graphics were positively perceived. The game was also perceived as being fun, and most students were interested in the game, concentrating while playing and feeling that the time spent (learning about ionic bonds) just slipped away. The grand mean score of 3.78 fulfilled the success criterion (threshold 3.41) concerning the engagement level for this game. However, the findings for the learning objectives were not satisfactory. The conclusions of the knowledge test revealed that in only two of the four questions, the number of correct answers was higher than the number of incorrect answers. The questions asked were though rather tricky. Specifically, naming five ionic bonds as an open-ended question was difficult for most students, possibly due to a misunderstanding of what was asked. The feedback from the students indicated that they enjoyed the game, and most students could see themselves playing it for educational purposes. Logistics regarding the test setup proved to be a challenge in the evaluation of multiple participants simultaneously. However, there seem to be some good results linking educational engagement with an auto battler game, with future work in making it an online synchronous multiplayer match so players can play against other classmates and friends, increasing competitiveness.

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