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Innovating Higher Education via Game-Based Learning on Misconceptions

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Abstract: In recent years, serious games and game-based learning have received growing attention in educational contexts in general and science teaching and learning. They play an especially prominent role in higher education, where they are used to promote content knowledge as well as higher order cognitive skills and competencies such as communication, collaboration, or problem solving. Despite some known positive effects of serious games on learning, critical voices claim that the objectives of a specific game often do not match the learning objectives and that the games focus on entertaining much more than learning. Considering these arguments and some general guidelines of using games in (higher) education, we developed a game on typical chemical misconceptions based on the popular game "Activity©" using Participatory Action Research. The game was developed based on the contents of a seminar on misconceptions for pre-service teachers (M. Ed. students) in a northern German university. It covers seven content areas where misconceptions are most prevalent and therefore aims at contributing to pre-service teachers' Pedagogical Content Knowledge (PCK). The students are supposed to draw or mime specific misconceptions. Initial trials in three university courses showed a very positive perception of the game.

Keywords: gamification; professional development; pre-service teacher training; misconceptions; action research

1. Introduction

Prominent psychologists and educational researchers such as Montessori and Piaget have acknowledged the value of playing for the development of children for hundreds of years [1]. Vygotsky [2] described games as providing opportunities for children to experience scenarios they are not yet able to live through in real life. Thus, the importance of games for one's development has led to the inclusion of game-based settings for learning purposes [3] both in lower and upper secondary as well as in higher education. When studying the extensive literature on gamification and game-based learning, it becomes obvious that the educational goals described in the literature are quite diverse and range from the promotion of content knowledge to motivation towards fostering collaboration and argumentation skills [4]. On the other hand, the evidence on actual learning outcomes fostered by games remains quite inconsistent [5]. Nevertheless, there undoubtedly are positive effects of educational games such as an increase of motivation as well as some quality criteria which can help to create games that are not only entertaining, but also promote specific educational goals [6].

This paper describes the development and implementation of a game in a higher education setting for pre-service teachers on typical misconceptions in chemistry. Although there is a number of publications dealing with the inclusion of both digital and analogue games in higher education teaching and learning, to our knowledge, there are no suggestions on games explicitly for prospective science teachers to learn about misconceptions for their future job as chemistry teachers. Our game follows the mechanics of the popular family board game "Activity©" in which the players must explain, draw, or act a specific term—in our case a typical misconception from a specific chemical domain. The game was developed during a seminar on misconceptions using Participatory Action Research [7]. After the first cycle of development, the ways of describing a term were reduced from three (explaining, drawing, acting) to two (drawing and acting). In this paper, we will outline the theoretical framework on which the game development was based, describe the development as well as the rules of the game, and outline initial results from the implementation of the game in two German universities.

2. Theoretical Framework

The literature from the last decade indicates that game-based learning has received increasing attention in the educational context [6]. The term "serious games" is often used to describe educational games. In 1970, Abt [8] defined the term as "games that have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement" (p. 9), but, at the same time, pointed out that the amusement aspects also do not need to be neglected. Serious games are also closely connected with game-based learning (GBL) [9]. While GBL includes a wider variety of games such as traditional board and card games, the term "serious games" primarily, but not always, focuses on digital games nowadays [6]. It is certain that both terms describe activities that employ game mechanics for learning purposes. Game-based Learning can furthermore be combined and is often mentioned together with similar learning methodologies such as Collaborative-based Learning [10], Problem-based Learning (PBL) [11] and Project-based Learning [12]. The present study can be most likely referred to as a project of gamification. Gamification is commonly defined as changing processes that are not games through implementing a game or at least elements of one [13,14]. Here, game mechanics are explicitly used to follow concrete educational goals and solve specific problems [3]. When it comes to overarching theories, gamification elements making up effective games for learning can be linked to the central theories of constructivism [15], namely social constructivism (and communities of practice) as well as situated learning [16].

Commonly mentioned elements for gamification in learning and education are story, dynamics, mechanics, collaboration, goal-oriented design, set of rules, and technology [3,17], some of which are mostly applicable to digital games. However, this does not mean that specific elements must be used for gamification in learning and education. Also, using many gamification elements does not ensure more effective gamification or better results [18]. Considering the given conditions, educators should choose necessary gamification elements to create an integrated solution that solves problems in learning and education [3].

Sometimes games in the school context are criticized for overemphasizing the purely entertaining and competitive aspects of the game while neglecting the intended learning outcomes [19]. Therefore, it is of great importance to thoroughly plan the educational use while designing or applying a game setting. On the other hand, games have certain positive effects such as the increase of motivation due to the competitive character [20] or fostering problem solving as well as other higher order thinking skills [3]. Nevertheless, the educational value of games in terms of their effect on content learning remains uncertain [5]. Based on the research findings available so far, Tsekleves, Cosmas, and Aggoun [6] as well as Kim, Song, Lockee, and Burton [3] developed several quality criteria that educational games should possess to increase the probability of both motivational as well as educational effects. These quality criteria are in line with the gamification elements mentioned above and were applied by us to direct the creation of our game. Games in educational frameworks should, among other aspects, be aligned with the curriculum, have clear learning goals like progression or repetition, be interactive, and contain aspects that can be used for assessment and feedback purposes, and thus allow students to check their own progress.

For the subject of chemistry in the context of higher education, several educational games have been suggested in the literature recently. For instance, Stringfield and Kramer [21] described a review session of a chemistry course for non-majors in the format of a quiz show (similar to "Who wants to be a millionaire") which had a positive impact on the performance of the students in the final exams. Sousa Lima and colleagues [22] recently introduced an app-based game on chemical nomenclature which includes a task database with over 700 questions. Generally, the science-based games found in the literature (also from other domains like biology, [23]) are not explicitly aimed at pre-service teachers and are designed to promote content knowledge rather than aspects of Pedagogical Content Knowledge (PCK). Kavak and Yamak [24] developed a card game on the topic of laboratory equipment which they tested with 18 pre-service teachers in a laboratory course—here, pedagogical aspects were also not the focus. Thus, the novelty of our study is that we used gamification elements to innovate a session on misconceptions explicitly for pre-service chemistry teachers by creating a game with a clear learning goal. So far, no games have been described in the literature that focus on PCK aspects. As a research methodology, we used Participatory Action Research to guide the development process.

Our claim is that more research as well as research-based development of games for pre-service teachers is needed. Therefore, we set out to develop a game for higher education that meets the above-mentioned quality criteria and can be flexibly implemented into the framework of learning about misconceptions and therefore develop pre-service teachers' PCK [25,26]. Misconceptions have been one of the most prominent, but also one of the most complex, topics in science education research and thus also in science teacher training for almost 50 years [27]. Being aware of students' common misconceptions is a substantial part of teachers' professionalization. This awareness is the basis for developing diagnostic skills and thus avoiding potential learning difficulties [28]. Our game idea might help pre-service and in-service teachers to think about misconceptions in an unconventional, sensory, and playful way that consolidates their existing knowledge.

3. Methodological Approach

3.1. Objectives

Our guiding question for the current stage of the research project was: To which extent is it possible to develop a game for pre-service teachers on typical students' misconceptions using Participatory Action Research? This paper describes the development process of the game as well as first cycles of the implementation of the prototype in two German universities, which resulted in major transformations of both the game procedure as well as the concrete formulations of the tasks. The effectiveness of the game concerning learning outcomes and/or motivation has not been researched yet. As mentioned above, the game was developed using Participatory Action Research (PAR) [7]. Action Research is a strategy that uses research to address problems arising in practice and thus solve them, resulting in improving practice. This happens in a cyclical and iterative process of planning, implementing, evaluating, and reflecting [29,30]. In our case, the project team involved two science education researchers (who at the same time are high school teachers) as well as the pre-service teachers. The development process took place in the context of a seminar on misconceptions regularly held at a middle-sized German university. The seminar is aimed at students studying to become chemistry teachers in the first year of a two-year Master of Education program. Seven of the twelve seminar sessions were dedicated to topics where misconceptions arise most frequently. The starting point of this PAR project was that one of the researchers lacked a comprehensive summary of the seminar's content as the amount of content in these seven sessions was very broad and condensed. As a consequence, she decided to create a card game trying to summarize the most prominent misconceptions.

3.2. Action Research Based Game Development

In the first cycle of game development, tasks were formulated based on the rules of the game Activity© where specific terms must be explained, drawn, or acted out in a pantomime. Seminar observations in each session formed the tasks creating different game cards inductively. The misconceptions which were discussed in the sessions were all derived from the extensive body of literature on this topic [31,32]. The first prototype comprised a set of 50 solely text-based cards and was used for a first trial with a group of 12 students at the end of the winter semester 2019. After playing the game, the students were asked to fill out an evaluation questionnaire containing open-ended as well as Likert-scaled items. The questionnaires were filled out by all students voluntarily. Section 4.1. describes the detailed results of the questionnaires from all the development cycles. Overall, the developed game was carried out at the end of January 2019, in April 2019, and in February 2020 at two universities in Germany. The total sample size was n = 36 due to the fact that the number of students who study chemistry education on a more advanced level is limited in Germany, resulting in only three groups of students who actually played the game so far. The action research process led to changes in the game-design and in certain rules of the game itself. The final version of the game contains 42 cards. An overview of the process is given in Table 1. The changes were made based on the results of questionnaires in both groups and a group discussion in the first group only, which is appropriate for action research processes [33]. The group discussion was conducted with four selected students from the first group and partly transcribed to get the information for improving the game. Here, every single card was discussed with the students to get their feedback and improve the game.

Table 1. Overview of the research and development process.

Cycle	Methods	Consequences
January 2019, University A	Implementation of the game Questionnaire & group Discussion with one group	Rework certain tasks and make changes in formulations Change categories of certain tasks Reduce the number of categories from three to two (leave out "explain")
April 2019, University B	Implementation of the game Questionnaire	Rework a few tasks and make changes in formulations
February 2020, University A	Implementation of the game Questionnaire	Slight changes in formulations

To play the game, a certain amount of knowledge on misconceptions is required in order to guess the misconception. Before attending the seminar and playing the game for the first time, the students were given information about the game to prepare themselves and to revise the content of the seminar. This can be also seen as a way to apply soft pressure on the students—they must revise the material in order to gain a good result in comparison to their peer-group [20,34].

4. Results

4.1. Results of the Feedback Questionnaires

The first item of the questionnaire asked for a self-evaluation on the statement "Assess your knowledge of misconceptions in chemistry classes on a scale from 1 to 10 (1 = poor; 10 = very good)." This is the only item that was assessed both pre and post. The mean value pre was 6.8 (SD = 1.31) and post 7.6 (SD = 1.9), so there is a slight increase. The open-ended questions were analyzed by Qualitative Content Analysis (QCA) according to Mayring [30]. Summarizing qualitative content analysis was used, which is a cyclical, multi-step procedure for examining qualitative data. The data was first paraphrased to inductively identify common themes. These questions related to what students perceived they had learned, the positive aspects of the learning environment, as well as any potential changes and improvements.

Approximately one-third of the pre-service teachers stated they have learned some new misconceptions, even though they had just attended a seminar on this topic: *"I learned that substances have properties while their particles don't. I also learned that electricity is not 'consumed' and about the concept of 'Horror vacui'."* All of the pre-service teachers emphasized that the game was a good way to repeat the misconceptions in a fun and not overly time-consuming way: *"I did not learn actually new aspects, but the game was a good repetition of the respective subject areas where misconceptions can arise."* Some of the respondents were able to self-diagnose where they lacked understanding and awareness of misconceptions: *"I could see in which areas there is a need to catch up. During the preparation phase I had to deal with the misconceptions intensively which led to some kind of consolidation of knowledge."* Four pre-service teachers explicitly emphasized the importance of a clear and coherent explanation and visualization when presenting a certain misconception—an issue which is, undoubtedly, also important in the school context: *"Again, I became aware of the importance of linguistic accuracy when explaining and also when understanding the misconceptions."*

When asked about the aspects they particularly liked, almost all of the participants praised the general game-based design of the session: *"I liked the idea of the game, the repetition of the topics was designed in a playful way, so I think the information will stay in the memory longer"* or *"The competitive setting motivated me a lot – it was a lot of fun."* Some of the pre-service teachers emphasized specific parts of the session they particularly liked: *"I really enjoyed the preparation phase because of the intense discussion: What is important about this misconception? What is happening in the students' heads?"* About 20% of the pre-service teachers named a number of aspects that constituted a positively connotated playing experience: *"One has again delved into the theory on misconceptions and exchanged ideas. In the conversation during the preparation phase, we have already discussed (a little) how to deal with the misconceptions in the chemistry classroom. I must say I also underestimated some of the misconceptions before playing the game—I thought I would just tell the students they were wrong, and I probably would not have considered them when planning my lessons. Playing in a team against others was fun, many different misconceptions were addressed, and a deeper individual reflection was stimulated."* Again, some participants pointed out (among others) the self-diagnostic effect of the game: *"I liked the three [answer from the first cycle] categories: explaining, drawing & pantomime—these are different representations of misconceptions; playful confrontation with misconceptions, whose explanation reaches "flow" state; it becomes clear for me at which points I have to repeat the contents of the seminar again without being in a test situation (less stress); classification into different levels of difficulty."* To sum it up, in the feedback questionnaires, most of the students stated that the game was not only fun to play, but also showed a good overview of the broad field of misconceptions. Overall, our observations showed that the students were more willing to engage with the seminar contents after playing the game. More positive features of game-based learning which have been addressed by the implementation of the game are a diversification of learning experiences, the stimulation of peer-level discussions among the students, and a reduction of complexity.

The main negative feature of the game that came up in the first trial with a group of twelve students was the difficulty to explain misconceptions. Half of the group stated that it is very challenging to rephrase misconceptions without drifting into incorrect terminology or giving too many clues by prompting crucial technical terms *("I would criticize the "explaining" category! Some tasks were too hard because I did not know which words to use without already providing the correct answer.")*. This problem turned out to be even more pronounced during the group discussion with four selected students during which we requested feedback on every single card. Here, the explanation cards were criticized by far the most, so we decided to change them into pantomime/drawing cards or eliminate them completely, which resulted in the final version of the game encompassing 42 cards (an English version with 36 cards can be found in the Supplementary Material). During the group discussion, the pre-service teachers also provided feedback on possible illustrations for the cards (see Figure 1 for an example). The difficulty was that the illustrations should be chosen in such a way that they do not induce further misconceptions and do not influence the players. For instance, we decided not to illustrate the cards on chemical equilibrium with an image of scales as they stand for a static and not a dynamic equilibrium.

The Likert-based items focused on various aspects of motivation, interest, and fun, the perceptions of the game itself as well as the whole session, and the choice of tasks for the cards. Answers to the Likert questions were subjected to descriptive statistics, which is suggested appropriate for this kind of action-research-based design research, where evaluation is cyclical and aims more at understanding teaching practice improvement, rather than at producing hard data [33]. The percentage distributions from the Likert items were displayed in a bar chart diagram (Figure 1). The aim of this part of the questionnaire was to provide first insights into students' affective responses to the game. It also helped to obtain first clues as to whether such activities can lead to better reflection and increased motivation. The feedback was required to improve the game and the session itself. Overall, the students appreciated playing the game and did not consider it as time wasting. Most of them think that the misconceptions were well chosen and that the game provided a good summary of the seminar's content. Also, they thought that games can be used as a teaching method at the university level and perceived playing as motivating. At least some of the students fully agreed that they dealt with misconceptions more deeply by playing the game (Figure 1).

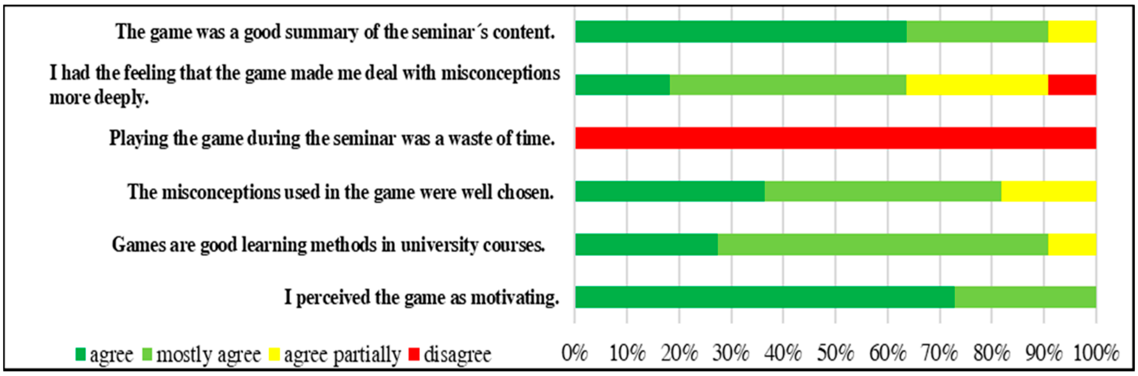

Figure 1. Selected students' feedback from the Likert-scaled items.

4.2. Final Structure and Rules of the Game

The three rounds of implementation resulted in the game: "FeVoAct" ("Fehlvorstellungsactivity"; German) which can be literally translated to "MisCoAct" ("Misconceptions Activity"). The game can be separated into three phases: preparation, playing, and determining the winner. In the preparation phase, the students get information on the game's rules and receive time to prepare for the playing phase. Generally, most students are familiar with the rules because they know the game Activity© (at least in Germany/our experience). For the playing phase, teams of students were formed. Here, every team received five game cards (example in Figure 2) and had to choose three out of those five cards (set of cards) to present during the playing phase. The cards were designed to have different levels of difficulty (three in total). The level is indicated by a red, yellow, or green test tube on the top of the card. Those three selected cards must include all three levels and both categories (drawing and pantomime). Every game card has a certain topic, category, description, and difficulty level (Figure 2). The topics are based on seven areas of misconceptions that can be found in the literature and that are included in the seminar sessions (see Table 2, left column). The card's topics are on top of the cards and numbered. The game has two categories: drawing and pantomime on three different levels which display the difficulty of the card. Also, every card includes a description of the task, e.g., draw a certain misconception. The lecturer of the seminar preselected the cards so that every set of cards consists of different categories, levels, and topics so that all students can fulfill their requirements. After the instruction, the students select their cards and exchange ideas on how to explain their misconceptions. Our game differs from the game Activity© in that aids may be used for the categories draw and pantomime. Within the draw category, students can write chemical elements or formulas. Within the pantomime category, students can prepare small signs e.g., to signal that they are an electron. Examples of the tasks are given in Table 2, right column.

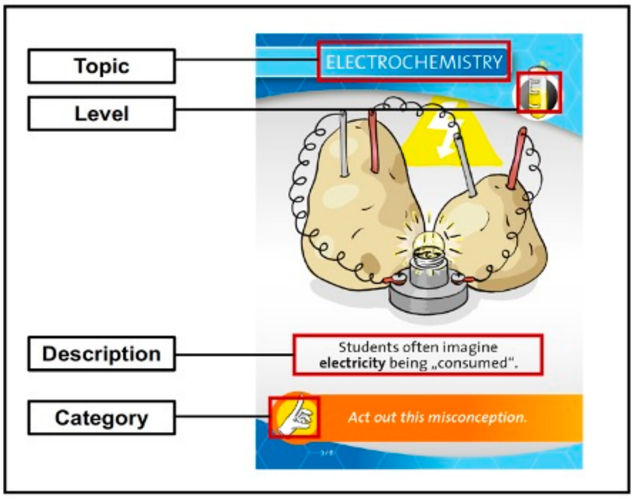

Figure 2. Example of a playing card (Pantomime). The learners have to present the misconception non-verbally.

Table 2. Overview on the different topics and an exemplary task.

	Tasks (Example)
Nature of matter	Matter is often seen as a homogenous mass (continuous substance) at the submicroscopic level. Draw the misconception of the continuum.
Chemical bonding	Learners often imagine salts having covalent bonds. Draw this misconception.
Acids and bases	A misconception regarding neutralization is that solid salt precipitates. Draw this misconception.
Electrochemistry	A cause for misconceptions may be that in the physics lessons batteries are displayed as "black box", which is not explained. Draw this cause.
Chemical equilibrium	Chemical equilibrium is often seen as something static and not dynamic. Mime this misconception.
Chemical reactions	Learners often think that a chemical reaction can be seen as a transformation from substances into energy (transmutation). Mime this misconception.
Models	Models are often seen as pure copies of reality. Mime this misconception.

After the preparation phase, the playing starts with all teams presenting their level one cards, followed by level two and three (increasing difficulty). If a group from the audience wants to guess which misconception is presented, they must signal this by raising a yellow card. The lecturer decides which answer is right or wrong. An example of a drawn misconception can be found in Figure 3. Here, the misconception is that properties of substances (in this case chlorine being greenish/yellow and toxic) are being transferred to the atoms of these substances.

There are several ways to score points in the game. First, the group that guessed correctly received points depending on the card's level. Second, the total time taken by each group to explain their misconceptions after three rounds was calculated. The group with the shortest overall explanation time got the most points. This should lead to a fair winner, who is able to both explain and guess well.

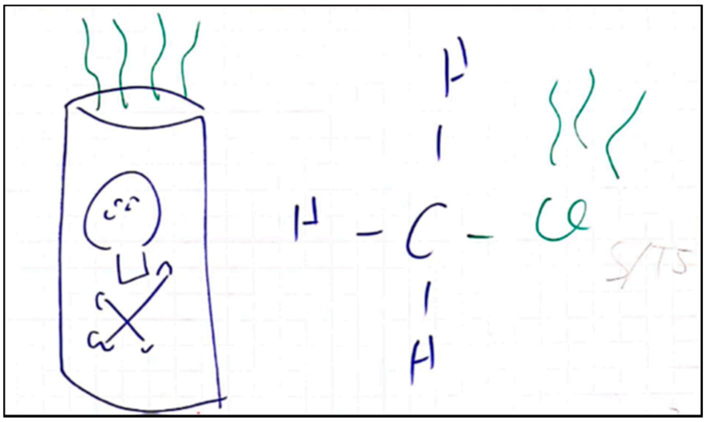

Figure 3. Example of a drawn misconception.

5. Conclusions and Discussion

Undoubtedly, knowing about misconceptions is of great importance for future chemistry teachers. "MisCoAct" showed potential to be a fruitful way of consolidating and repeating the most frequently occurring misconceptions. Our game implements common features of gamification in learning known from the literature [17] and produces an enjoyable learning experience without overemphasizing the entertainment factor [19]. The game fosters collaboration between students in a dynamic and competitive setting and features a clear and simple set of rules. According to research, the competitive aspect in particular leads to increased motivation. Although we did not use an explicit instrument to measure motivation, the students' answers to the open questions show that situational motivation was present during the game session. Their active participation in the game can be also seen as a sign of increased motivation [4]. Many participants emphasized that the game provided a good repetition and summary of the seminar content. This shows that our game combines the subject matter to be learned with the playful setting—a crucial feature of an educational game, according to the literature. Another positive feature of the game that emerged from the results of the questionnaire *("it becomes clear for me at which points I have to repeat the contents of the seminar again without being in a test situation (less stress)")* and is in line with the literature on game-based learning is that games provide a safe environment to apply knowledge abstracted from a test situation [17,35]. Our game fulfills further theory-based criteria such as clear alignment with the curriculum for pre-service teacher education at the corresponding university, transparent and manageable learning goals (mainly the revision of content), interactivity, and the possibility for the pre-service teachers to check their own progress.

In the seminar's context, "MisCoAct" provided a productive, motivating, and time-effective way of summarizing the content. The design of the illustrations for the game was professionally created with financial help from the German Fund of the Chemical Industry (FCI) of the German Chemical Industries Association (VCI). Generally, games in pre-service teacher education can provide opportunities to reduce the complexity of certain areas of PCK and help the students to self-diagnose gaps in their own PCK. This is where our game stands out from the games for chemistry students on the tertiary level described in the theoretical framework [21,22,24]—it does not focus on pure chemical content knowledge, but on PCK. As games are also often incorporated in the school context, we believe that well-designed educational games implemented in higher education will motivate future teachers to incorporate GBL in their future classrooms.

6. Limitations

As already mentioned, concrete effects on learning of the game were not measured yet, for instance via performance tests in a pre- and post-design or at least with a follow-up test. This can be our next research step. Since the sample is too small to generalize the findings, we plan to broaden the sample and include other neighboring universities. On the other hand, generalization is neither the aim of this paper nor of Action Research in general. With the help of Action Research, it was possible to develop an engaging game that incorporates the common chemical misconceptions and presents them in a more physical, uncommon way. The case presented here is limited to the German educational context, but we believe that knowledge of students' misconceptions should play a role in teacher education all over the world. The study was not connected to an evaluation of how this lesson plan interacted with learning the basic chemistry behind the misconceptions, since this was not the focus of the game setting.

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