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RESEARCH ARTICLE

Acid Base Global - An Escape Room to Learn about the Chemistry of Acids and Bases

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In recent years the popularity of educational escape rooms has increased. To escape as fast as possible, learners must solve different puzzles in a collaborative manner. The puzzle structure is reminiscent of problem- or inquiry-based learning. Therefore, educational escape rooms are particularly suitable for science education. This paper describes the development and first evaluation of an educational escape room for the chemistry classroom called *Acid Base Global*. *Acid Base Global* deals with typical acid-bases reactions, neutralization, chemical formulas, the pH-value, identification of acids, bases and ampholytes, as well as the Brønsted-Lowry-theory. It can be used to review and consolidate content knowledge and to diagnose learning difficulties. *Acid Base Global* was first implemented in secondary chemistry courses consisting of 61 students. A questionnaire containing six open questions and 16 Likert-items was used for evaluation. All groups were able to escape within the given time limit, although the format was challenging for the students. Overall, learners were interested in the game concept and found it to be a fun approach to repeat and apply their chemical knowledge in a different way.

Keywords: Gamification, Problem-based Learning, Escape Room, Acid-Base Chemistry

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1. Introduction

Playing is a fundamental aspect of human behavior that can be found in various forms across all cultures and societies worldwide (Roberts, Arth & Bush, 1959). Prominent psychologists and educational researchers, such as Montessori and Piaget, have recognized the importance of playing for children's development for many years (Murray, 2018). Vygotsky (1980), for example, believed that games provide children with opportunities to experience scenarios they are not yet able to encounter in real life. Because of its importance, game-based learning has been incorporated from primary to higher education (Kim, Song, Lockee, Burton., 2018). Elements commonly used in gamification in learning and education include story, dynamics, mechanics, collaboration, goal-oriented design, set of rules, and technology (Aynsley, Nathawat & Crawford, 2018; Kim et al., 2018). However, it is not necessary to use all these elements for effective gamification, and using many elements does not guarantee better results (Mora, Riera, González & Arnedo-Moreno, 2017). Therefore, educators should choose the necessary elements to create an integrated solution that addresses problems in learning and education.

When someone plays, he or she often “escapes” from their everyday experiences and become fully absorbed in the game world. This concept is referred to as "flow theory" (Csikszentmihalyi, 1990), where the state of "flow" is described as being completely immersed in a task that is both challenging and enjoyable. A current trend in gaming that embodies this concept is the escape room, where players are fully immersed in a game world and attempt to solve puzzles to escape. According to Nicholson (2015), an escape room is a live-action adventure game in which players have to work together to solve various puzzles and tasks. The goal is to escape from one or more locked rooms or to complete a story-based task, such as developing a cure for a disease or defusing a bomb (Nicholson, 2015). The game is accompanied by a game master, who informs the players about the rules, the goal of the game, the general process as well as safety measures. By locking the door and starting the timer the game begins. To move forward, players must search the room for clues, decipher them and solve the puzzles. Meanwhile, the game master observes the participants and provides help if needed or requested. The game automatically ends when the time runs out or the players reach the game objective. Sometimes a debriefing session follows the end of the game. In the debriefing players get a chance to talk about their experiences, struggles, successes, and feelings within the escape room.

Puzzles are the core game element of escape rooms. In general, a distinction is made between mental and physical puzzles (Wiemker, Elumir & Clare, 2015). The latter are time consuming and require more space because part of the room or physical objects must be moved or manipulated in a specific way to solve the puzzle. The cognitive load is much higher in mental puzzles in which clues must be discovered, decoded, and put together to find a solution. Most of the time there is a great variety of puzzle types to address different skills, interests, and experiences of the participants. Nevertheless, three basic components can be identified: a problem or a challenge, a hidden solution, and a reward (Wiemker et al., 2015). Usually, the solution is hidden in the room or the puzzle itself. Players receive the reward after solving the puzzle or completing the challenge. This leads to new puzzle pieces, objects, rooms, or hints. Well-designed puzzles can be solved with the available clues and objects in the room and are embedded in the theme and/or story of the game. With increasing popularity escape games have been further developed. First-generation escape rooms only consisted of logic puzzles with varying degrees of difficulty. Over time different puzzle types, technical as well as electric components and a background story or theme were included, leading to more complex room designs (Wiemker et al., 2015). Lately more web-based, augmented, or virtual escape rooms have been appearing due to increasing

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digitalization. Nowadays, escape rooms can be found in any mayor city and exist in many different formats, such as escape books, breakout boxes and home kits and virtual or augmented reality escape rooms. In addition, new fields of application were discovered including cooperate training and formal as well as non-formal education (Fotaris & Mastoras, 2019). In an educational setting, escape rooms are a creative learning environment that is known for promoting interdisciplinary skills such as collaboration, communication, lateral thinking, and problem-solving skills (Looking@Learning, 2015a). The core of the game concept is maintained and adapted to the school setting. This way, students' needs are considered and both content- as well as process-related skills are integrated into the game. Educational escape rooms can be designed for any subject matter and used at all levels of education, be it kindergarten or university (Looking@Learning, 2015a; Lathwesen & Belova, 2021).

Escape Rooms in (Science) Education

One of the primary goals of educational escape rooms is the playful learning of new subject matter and skills as well as the repetition, deepening and transfer of existing knowledge. In addition, the students are made aware of the effects of their own behavior on themselves and others. Also, self-confidence, social interaction and the appreciation of different perspectives are to be strengthened (Looking@Learning, 2015a). It is important to mention that the puzzles do not have concrete instructions. Instead, the work assignment is only implied in the clues and the puzzle itself and must be discovered by the leaners (Nicholson, 2015). This can be a major challenge, especially for students who have no previous experience with escape rooms and who are not used to such open settings. Due to spatial conditions and the size of the learning group, the game concept has to be adapted to implement educational escape rooms in school (Nicholson, 2015), where they usually consist of only one room (Fortairs & Mastoras, 2019). Therefore, it is important to clearly distinguish the game objects from the other objects in the room, e.g., by putting a logo on them (School Break, 2021).

The thematic design of the game environment also needs to be reduced, as educational escape rooms need to be spatially reversible and financially affordable (Sundsbø, 2019). In addition, adjustment is required in terms of group size. While commercial escape rooms are designed for a group of two to six persons (Nicholson, 2015), educational escape rooms are usually played by several small groups at the same time in one room. The room can still be used, for example, by color-coding the clues and puzzles for each group. Despite the necessary modifications, educational escape rooms have great potential in the field of education. The game concept accommodates different learning styles and paces, appeals equally to both genders and is a student-centered, creative learning environment. The educator takes over the role of the game master, observing the students and supporting their learning process by request. This way, learners are responsible for their own learning process and independently develop, try out and evaluate their own ideas and strategies by using their knowledge and skills in an unconventional manner (Looking@Learning, 2015a). Furthermore, educational escape rooms promote interdisciplinary skills in a fun, student-active way, which can have a positive effect on students' motivation (Wiemker et al., 2015).

A recent review on escape rooms in science education (Lathwesen & Belova, 2021) revealed that there are plenty of examples already available for different subjects, such as chemistry (e.g., Nephew & Sunasee, 2021), physics (e. g. Tulha, de Carvalho & Coluci, 2019) or biology (e.g., Healy, 2019). They greatly differ in their complexity and setup, ranging from simple escape boxes to complex settings involving several rooms. Despite the great number of proposals, our impression was that that the escape rooms published so far were mainly adapted to the needs of a specific course or institution – this is understandable, but limits transferability of such proposals to other institutions and learning groups. From our point of view, the science education community would benefit from approaches systematically covering standard topics that could be easily transferred to other institutions. Moreover, there is a need for more STEM escape rooms in secondary education. The escape room presented in this paper fulfils these two criteria: it provides a way to consolidate knowledge on maybe one of the most central topics in chemistry education – acids and bases – in secondary school.

Acid Base Global

Development of the escape room Acid Base Global

The educational escape room *Acid Base Global* was developed based on the "escapED Framework" (Clarke et al., 2017) and the tutorial of the "Looking@Learning" (2015b) project. *Acid Base Global* can be played in a regular classroom by a group of 12 up to 30 students. The escape game consists out of 20 puzzles and can be used at the end of a lesson plan about acids and bases or as a revision of this topic in upper secondary classes. The students have to describe the acid-base definition according to Arrhenius as well as Brønsted, recognize corresponding acid-base pairs, name properties of acids and bases, define and calculate the pH value and connect it with the autoprotolysis of water. They identify acidic, alkaline and neutral solutions theoretically with pH scales or experimentally using indicators and relate the results to the presence of the respective ions. In addition, they formulate initial word and symbol equations, including those of typical acid-base or neutralization reactions. They also have to conduct titrations and calculate the concentration of a specific solution. Therefore, an application of the educational escape room is possible in the upper and lower secondary school. The game scenario starts with students being invited into the fictional company *Acid Base Global*, where they end up being locked in the company's lab as test subjects. To escape from the laboratory, students must collaborate in groups of two to five to figure out the code for the locked door by solving five puzzles within 90 minutes.

The escape room uses group boxes containing nearly all the necessary clues, puzzle components, lab equipment and household chemicals, excluding the introductory puzzle and color-coded envelopes. This is an advantage especially for smaller classrooms, inexperienced learners and for the teachers who set up the activity. The groups do not compete against each other, they can only

escape together. By solving the three individual puzzles each group receives one of the code numbers. The class must put the numbers in the correct order to decrypt the multi-digit code and escape. Therefore, students who have completed their tasks quickly are encouraged to help the remaining groups to escape as fast as possible, if they have already finished all of their puzzles. Not all group puzzle sets (puzzles a, b and c in **Figure 1**) have to be played. The code and the number of puzzle sets can be adapted to the size of the class and the chosen mode (collaborative or competitive). Competition is still possible by dividing the course in two and assigning selected group puzzle sets twice. This way, one half of the class competes against the other half. Another option would be to let different classes compete against each other. The escape room can be conducted in any room and adapted to any class size, uses household chemicals, and addresses the standard secondary chemistry topic acids and bases. For the above-mentioned reasons, the escape room can easily be transferred to other institutions.

The structure of Acid Base Global

Before starting the activity, the teacher should familiarize students with the game concept and rules. After that the narrative is read aloud and the timer starts. Each group must solve an introductory puzzle, a group puzzle set and the final meta-puzzle during the escape game (**Figure 1**). Each set consists of two theoretical and one experimental puzzle. Most experiments only use everyday household chemicals to identify acids and bases, which reveals a hidden message. Group boxes and envelopes must be prepared by the teacher in advance. Additional props, such as laboratory glassware, a pH scale, a chemistry book, a company logo, or visitor badges, can be used to provide additional help and to decorate the room matching the background story. This creates a more immersive game experience. In general, students may use anything in the room to solve the puzzles, unless the teacher states that only objects and materials in the respective group boxes may be used.

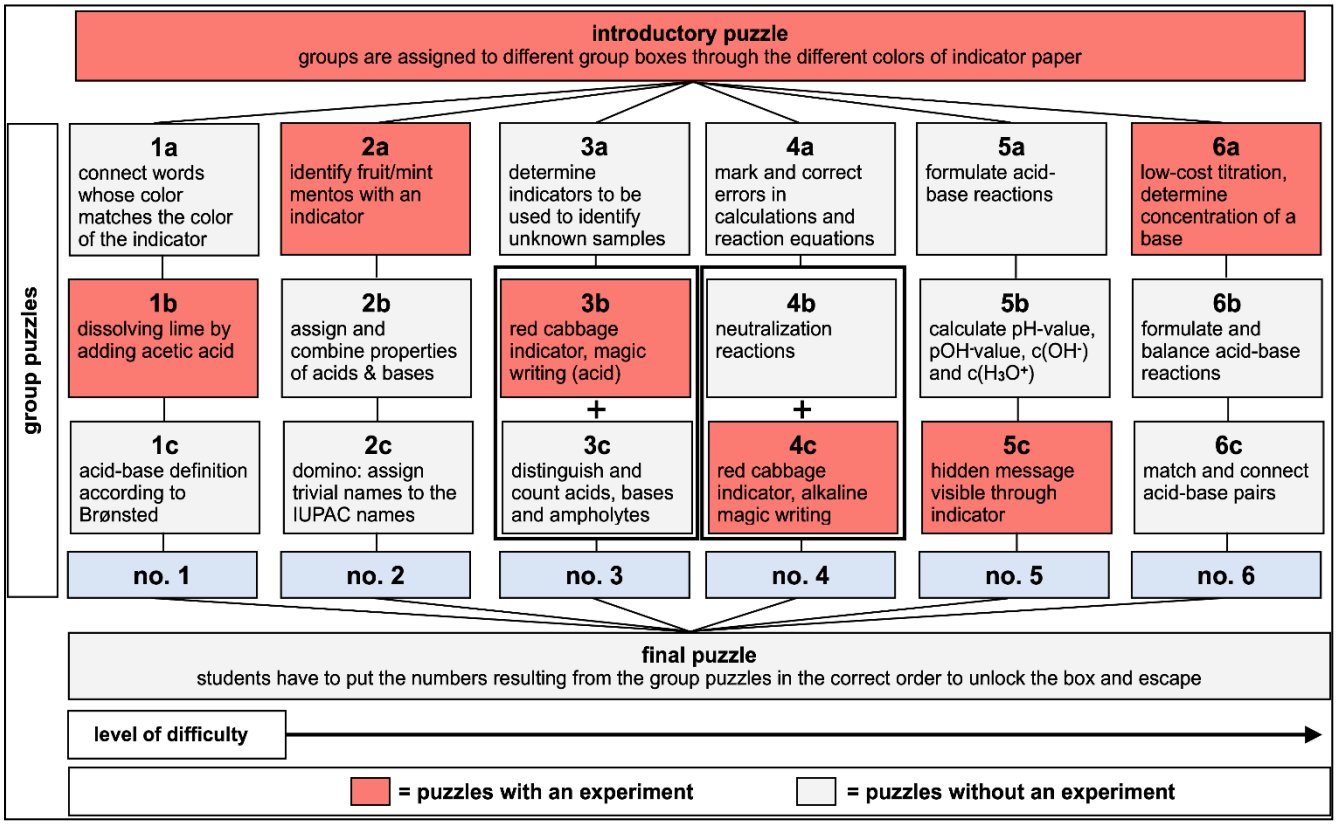

Figure 1. Structure of *Acid Base Global*

Students have to identify clues and hints within journal entries and company notes in order to figure out the work instruction. Some clues in italics or capitals are easier to find then others. To solve the puzzle learners are allowed to glue, cut up and mark all materials in the group boxes and use everything accessible to them in the room (may be restricted to objects containing the company brand or the group boxes). While students should be motivated to solve the puzzles on their own without any help, they can use clue cards if they are stuck on a specific puzzle for longer time intervals. Two different kinds of clue cards are available for the students: cards that are specific for each puzzle and or a teacher joker. A certain limited set of clue cards for each group or a time restriction can be useful to prevent students from seeking additional help too quickly. Compared to regular chemistry lessons the hidden work instructions can be challenging for the students. However, a main feature of the game concept is deciphering clues and figuring out what to do. Practicing on one puzzle before playing the whole game can help the students to familiarize themselves with the game concept. The teacher only observes the game as the „game master", while students work and check their answers independently through the locks.

Instead of actual locks or locked compounds, envelopes are used. An envelope may only be opened after the symbol, letter, or number on it has been found in the solution of the previous puzzle. If the solution is correct, the envelope contains a congratulation message, new puzzle pieces, objects and clues for the next puzzle. This enables students to progress in the game. If the solution is incorrect, students will receive a false number, letter or symbol, which will lead them to a wrong envelope. The envelope contains a notification of *Acid Base Global* or trial person 24 saying that something isn't right and gives them an additional clue. A wrong solution forces learners to rethink their answer and develop a new strategy. When the students solve the final puzzle which unlocks the box containing the room key, the game master stops the time and reads aloud the final story part for completing the escape room successfully. The box can contain an additional reward (e.g., chocolate). In the end, students may also receive a certificate just like in the commercial escape room. After students have successfully escaped, the teacher should moderate a debriefing session about the game and the learning experience so that leaners get the opportunity to discuss strategies, difficulties, and solutions.

Description of the puzzles and walkthroughs

In the beginning each group gets a household chemical, e.g., lemon juice or pipe cleaner, and has to identify the pH value and the corresponding color. Through this activity, students are assigned to their group color and one of six color-coded group puzzle sets. An example: Lemon juice has a pH-value of 2 and the color obtained with the universal indicator is red. The group that received the lemon juice has the group color red and must find the red group box and envelope.

All of the puzzles cover different subject content. The level of difficulty increases from the first to the last puzzle set. Educators should assign the puzzle sets depending on students' experience with the game concept and knowledge level. An alternative would be to have very heterogeneous groups by assigning students with different levels of knowledge, skills, interests and experiences with the game concept to the same group. By assigning the sets through the household chemicals, learners are not aware that they may have received easier or more difficult puzzles than their classmates. In groups no. 1, 2, 5 and 6 the walkthrough is linear, while groups no. 3 and 4 have a hybrid path (linear and open). Examples for an open structure are puzzles 3b and 3c. Each puzzle alone does not lead the students to the next clue or puzzle. Therefore, learners need to combine the puzzles to move forward in the game. In puzzle 3c they distinguish between acids, bases and ampholytes and count how many there are of each category. The number must be inserted into the formula that results from the experimental puzzle 3b so a code number is obtained. The short description of each puzzle can be found in **Figure 1**. In general, puzzles 4b, 5a and 6b deal with the formulation of chemical equations and have haptic elements, which can be moved by the students to complete or correct the equations. In puzzle 1a, 2b, 4a and 6c the correct, or, in case of puzzle 4a, the wrong answers must be marked and connected in a certain way, resulting in a symbol, letters or a number which "unlocks" an envelope.

Figure 2 shows the solution of puzzle 1a. Chemicals or everyday household chemicals are marked and connected with each other, if the color of the word corresponds with the color of indicator paper when put into the corresponding chemicals. The result is the triangle symbol above, which guides the students to an envelope containing the next puzzle. The envelopes are each marked with triangles of different shapes, orientations, and sizes. If students choose the wrong household chemical, they open the wrong envelope with a notification to try again, which provides additional clues. Puzzle pieces of the respective puzzles 1c, 2c, 4b and 5b must be put together or sorted in a certain way. In addition, mathematical skills are needed for puzzles 5b, 4b and 3c, such as basic calculation methods, logarithms and converting formulas. Each group puzzle set has one experimental puzzle (**Figure 1**). Mostly, acids or bases from household products are identified by using a pH indicator. As a result, a hidden message appears. No further instructions are given to conduct the experiment. Chemicals and laboratory equipment available in the group boxes as well as journal entries and notes from the fictional company can provide clues regarding the work instruction. **Figure 3** shows a note from *Acid Base Global* which gives the clue that the students must identify different types of mentos.

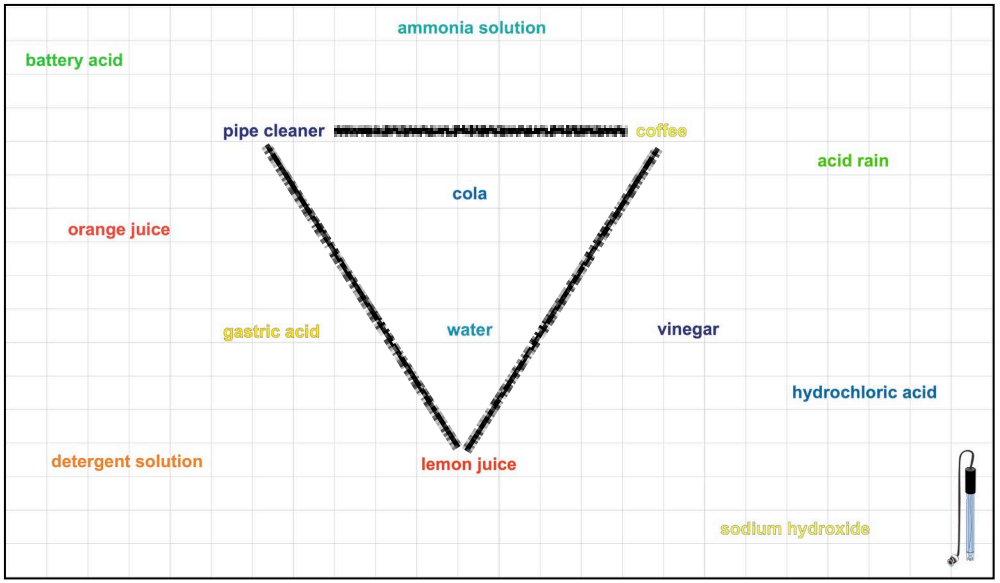

Figure 2. Solution of puzzle 1a from *Acid Base Global*

Acid Base Global

Lebensmittelversorgung
An: Versuchsgruppe 2

Sehr geehrte Versuchsgruppe 2,

es ist für uns von großem Interesse die Veränderung des menschlichen Verhaltens in Stresssituationen zu beobachten. Daher wäre es kontraproduktiv, wenn wir Ihnen uneingeschränkten Zugang zu Nahrungsmitteln gewähren würden. Sie verhungern zu lassen ist jedoch ebenfalls nicht im Sinne unseres Unternehmens.

Auf dem heutigen Menüplan stehen wundervolle Frucht-Mentos und erfrischende Minz-Mentos. Sie dürfen jedoch nur eine Sorte wählen. Beide Sorten sehen vollkommen gleich aus und unterscheiden sich nur in ihrem *Inneren*.

Bevor Sie Ihre endgültige Wahl treffen, sollten Sie wissen, dass wir die Frucht-Mentos mit Gift verfeinert haben. Dies erleichtert die Entscheidung ungemein, nicht wahr? Jetzt müssen Sie nur noch herausfinden, welche der beiden Proben *essbar* ist.

Mit freundlichen Grüßen

Acid Base Global

Acid Base Global

Food supply
To: Trial group no. 2

Dear trial group no. 2,

A great interest of ours is to observe how human behavior changes under stressful conditions. Therefore, you will have limited access to food. However, letting you starve is not in the spirit of our company either.

Today's menu includes wonderful fruit mentos and refreshing mint mentos. You will have to choose between the two flavors. Both mentos look the same and differ only on their *insides*.

Before you make your choice, you should know that we added poison to the fruit mentos. Now you just have to figure out which of the samples is edible.

Kind regards,

Acid Base Global

Figure 3. Notification from *Acid Base Global* regarding experimental puzzle 2a

All groups must work together to solve the final puzzle. They must put the code number each group received at the end of their puzzle set, in the correct order. For this, learners must solve a logic puzzle containing the analogies for the respective household chemicals from each group.

Implementation and Findings

Method

The escape room has been implemented in two upper secondary courses and a ninth-grade class in three different schools in northern Germany. So far 61 students tried out the escape room. All students volunteered to participate in the escape room and to provide anonymous feedback. In two trial groups acids and bases have been previously covered in the chemistry class, in one of the upper secondary classes the escape room was used at the beginning of a teaching unit about acids and bases. After a short instruction the story introduction was read aloud, and the timer was started. After about 50 to 70 minutes, the students of each class managed to unlock the box and escape from the lab. Immediately after that, they filled out a questionnaire consisting of five open-ended questions and sixteen four-point Likert-scale items. The Likert-items focused on interest, motivation, collaboration, the level of difficulty and the overall perception of escape rooms. Descriptive statistics was used to evaluate the Likert-items. The answers to the open-ended questions were analyzed based on the principles of qualitative content analysis according to Kuckartz (2018). After paraphrasing the students' answers, categories describing the content were inductively identified. To constitute a category system three rounds of coding were applied.

Findings and Discussion

In the beginning of the questionnaire, students were asked to answer six open-ended questions: (1) experiences with escape games in non-educational settings, (2/3) aspects they liked/disliked about the game, (4) difficulties encountered during the game, (5) an overview of the learning outcomes from the game and (6) skills necessary to successfully complete an escape game. First, students' private experiences were examined, since difficulties while playing the escape game occur due to a lack of experience with the underlying game concept or unfamiliarity with the puzzle structure. 35 students (57 %) indicated that they had never visited an escape room before or played a home version and therefore have no experience with the game concept. Knowledge of the game concept of escape rooms acquired through media was not considered as experience by most of the students. Based on the students' answers, quiet a few had heard about escape rooms before: "*I heard a lot about escape rooms, but have not been to one myself.*" Despite the increasing popularity of escape rooms, only 16 students had ever visited an actual escape room, six of them even more than once. In addition, five students already played a digital escape room and one student a tabletop escape room at home. All were members of groups who finished their individual group puzzle sets way before the rest of their individual class. But it could although be that these students were just good at the subject, hence the success. Based on classroom observation these groups often had a student acting as a group leader. They also approached the puzzles in a more strategic and structured way. This could be due to previous experiences with the game concept. It is noticeable that the students mainly referred to physical escape rooms and did not really mention any kind of escape games that could be played at home (e.g. virtually or as a board game).

Overall, students enjoyed the activity and "*had fun*". The puzzle structure, the creative learning environment, the collaboration and the gamified repetition of content were frequently mentioned when asking about aspects of the game students liked. Students generally found the escape room "*interesting*". Puzzles and solutions were perceived as *"creative"* and "*well thought through*". The majority of the students *"especially liked the puzzles"* because they "*had to think around the corner*" to solve them and apply their acquired knowledge in a different way. This could be an indicator for promoted lateral thinking. They also appreciated the "*variety of puzzle types*" and the

implementation of experimental puzzles: "*I really liked that we were able to make the hidden message appear […] with the help of the juice [cabbage indicator].*" According to nine of the students, the level of difficulty seems appropriate: "*[…] it was not too easy, but not too hard either.*" 17 students "*liked that [they] worked in groups.*" Working in groups as well as the use of color-coded group boxes restricted students' movements to certain areas of the room and was therefore perceived as helpful by the students in terms of organization. Seven students liked that "*each group did something different*" while still collaboratively solving the lock combination.

There is a great overlap when it comes to the difficulties and negative aspects mentioned by the students. When asked about what they disliked about the escape room, 20 students either left the field blank or pointed out that they "*liked everything about it.*" 22 students found it difficult and/or disliked "*not knowing exactly what to do*" and were unsure "*where to start or with which envelop*", in "*what order [they] need to do things in*" or "*which puzzle pieces belong together*". 17 of these students were part of groups with no prior private experience with the game concept. As mentioned before, the work instruction is hidden and must be discovered by the students using the clues and the puzzle components acquired during the game. Since this is a core game element of escape rooms, it should not be changed. Instead, the structure of the puzzles should be explained to the students with little or no experience, e.g. by solving a puzzle together as an example before the game starts. Solving a puzzle together familiarizes the students with the structure of the puzzles, shows them how clues and locks can look like, and lets them feel the initial feeling of not knowing exactly what to do. The teacher can also point out general tips, such as looking closely at the materials or communicating well within the group. It is also up to the teacher to decide how to organize the preparation phase. Different types of clues and puzzles can be presented or solved with the students. Especially at the beginning, it would be good to give more obvious clues through the narrative. Another solution would be to develop more clue cards or give the students more teacher jokers. This may not lead to the desired result since at least 20 learners did not use the provided clue cards nor reach out for help because they wanted to figure out the puzzles on their own. 14 students felt the difficulty level was too high. In contrast, 6 students did not like that some puzzles "*were too easy*" and too quick to solve. They belonged to groups each consisting of at least two members who have previously visited Escape Rooms. Lack of content knowledge was cited as a difficulty by 10 students. For the future, it would be better if students with more experience who have a good grasp of the subject content would be assigned to one of the more difficult group sets. This was not the case in any of the school trials. Seven students said that their "*teamwork did not work well*" and they did not have a strategy, which had a negative impact on solving the puzzles. To discuss the group dynamics, strategy, and difficulties of the hidden work instructions a debriefing session could be helpful (which did not take place in the trials due to time factors).

When asked about what they have learned during the escape room, the students addressed both content knowledge (46 %) and interdisciplinary skills (43 %). "*Nothing new*" was learned, however, previously acquired knowledge on the topic of acids and bases was "*repeated*" and "*consolidated*". Five students addressed the importance of carefully reading company letters and notes left behind and distinguishing what is important and what is not. Six students learned "*to be more patient*". This could be due to the puzzle characteristics of the game which force students to figure out what to do by themselves. One group of the first trial also learned that they should follow the game rules, because randomly opening the majority of the envelopes resulted in a "*mess*" of different puzzle components and clues.

Most students (24) also consider collaboration to be one of the most important skills for this format, followed by logical thinking (18), communication (9), creativity (6), patience (6), perseverance (5), enthusiasm (5) and concentration (4). This partially goes in line with Wiemker et al. (2015). Collaboration is deemed so important because "*you have to consider the ideas of others […] to find the solution as efficiently as possible*". In addition, strategic skills, independent thinking, memorization, correlation and lateral thinking were named by the students as being helpful to relate clues to the correct puzzle components, recognizing patterns and systematically trying out different ways. This is especially important when the students are solving open- or meta-puzzles. Surprisingly problem-solving skills were not mentioned at all. This could be because learners were unable to verbalize such an abstract concept as problem-solving skills immediately after playing the game, even if they had to use the skill in the game. This requires a high degree of self-reflection.

In addition, students had to answer 16 Likert-items. The results of the Likert-questionnaire are shown in **Figure 4**. In general, most participants enjoyed playing *Acid Base Global* (over 80 % agreed/agreed mostly) and perceived the escape room as motivating (over 80 % agreed/agreed mostly). However, only about 8 % of the students agreed and 21 % partially agreed that the escape room increased their interest in chemistry. Several reasons are possible. For example, the class may already have a high interest in chemistry-related contents. The question arises whether educational escape rooms can evoke a higher level of interest among students than regular classroom lessons. However, the focus of this particular escape room lays on repeating already acquired knowledge. Sustainable education, socio-scientific issues and professional orientation are not considered in the game but could improve students' interest and perceived relevance of chemistry in their everyday life.

As described above, collaboration seems to be one of the most important skills to successfully complete an escape room according to the students. Escape rooms are a great way to improve collaboration, communication and social interaction, which makes them attractive for cooperate training. However, only 67 % of the participants agreed or mostly agreed that playing *Acid Base Global* enhanced their collaboration skills. Almost the same percentage believed that each group member was able to equally participate in solving the puzzles. Together with the answers to the open-ended questions, this indicates that in some groups the dynamic did not work so well.

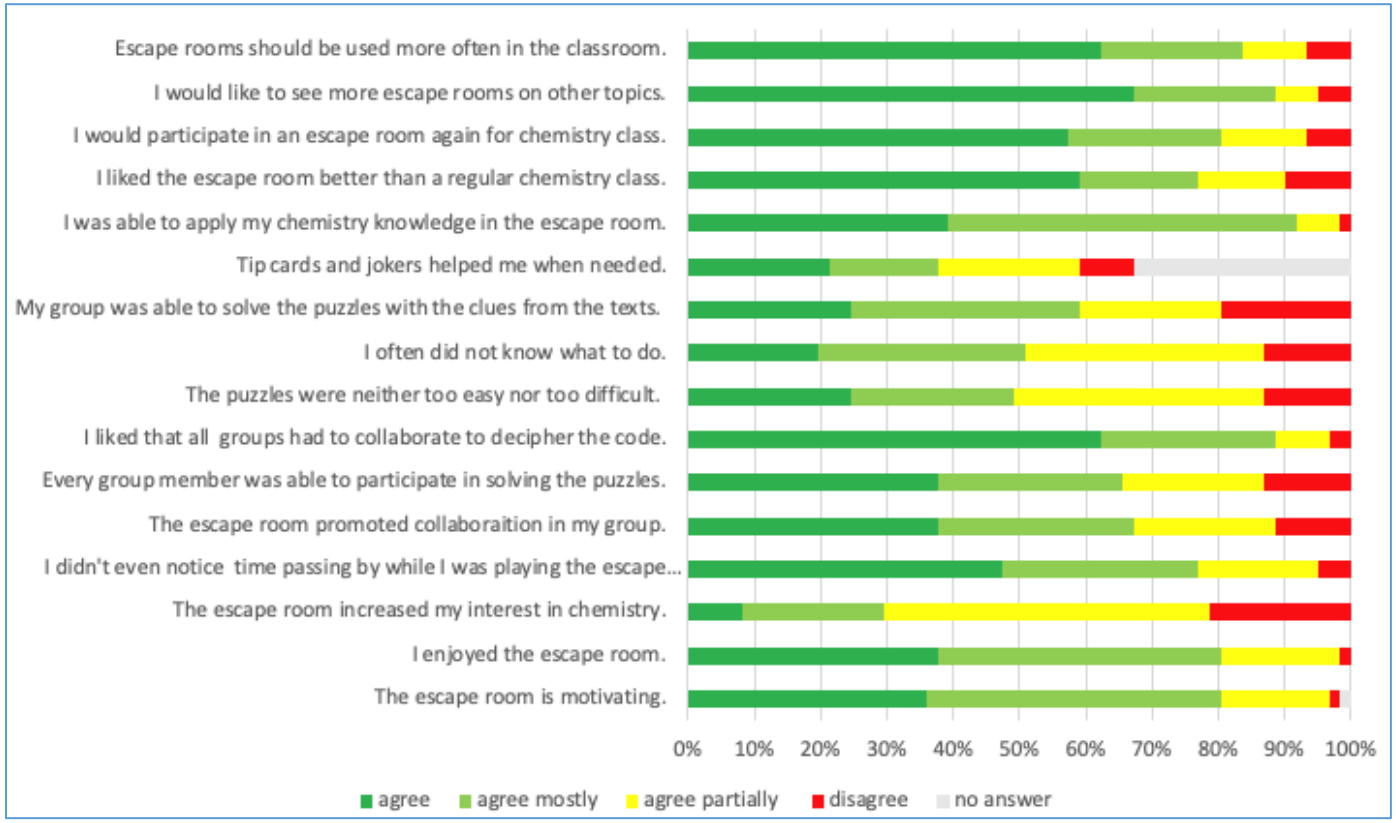

Figure 4. Students' feedback to *Acid Base Global* (n = 61)

Another reason could be the design of the puzzles so that not all group members are necessarily needed to master them. Puzzles consisting of several parts and requiring different knowledge areas and skills to be solvable are usually better suited for bigger groups. Based on teachers' feedback obtained after the game in an open format as well as students' responses to the open-ended questions, four groups had explicit problems working together as a group, e.g., no one claiming the position of the team leader, proceeding without a plan in an uncoordinated manner, not communicating enough, not considering the thoughts and ideas of individual group members. Nevertheless, most of the participants (over 85 % agreed/agreed mostly) still liked working together in their individual groups and collaborating as a class to solve the final meta-puzzle. Competition between groups does not seem to be missed by the students.

Some students found the puzzles too difficult, while they were too easy for others. The level of difficulty was appropriate for roughly 50 % of the participants. 20 % of these were students who were given puzzle sets whose content they had not yet covered in class. Difficult puzzle can frustrate students, too easy ones can be considered as boring. Both options might result in a distribution of the game flow and a decrease in motivation. In addition, roundabout 50 % agreed or mostly agreed that they felt like they did not know what to do, followed by 36 % agreeing partially. The reason for this is the puzzle structure of the escape room where the hidden work instruction has to be discovered by the students. Not knowing what to do is a normal and important feeling in an escape room, which is caused by the puzzle character and leads to a great sense of achievement when solving the puzzle. However, it should not last for a long period of time while working on the same puzzle. How long this feeling lasts from the students' perspective should be determined in future research. Two quick and easy solutions for this problem are assigning groups to a group puzzle set according to their learning level and providing more diverse clue cards. Also, more clues can be implemented in the narrative of the story or the game room. Students that did not use clue cards or jokers did not respond (33 %) to the item or partially agreed. One teacher noted in the debriefing that students would be more likely to use help cards if they were familiar with the method from regular class. Overall, about 8 % felt the clue cards were not helpful, with another 21 % partially agreeing and only 38 % agreed or mostly agreed that they were helpful. This should be an indication for us that we need to rethink the structure and organization of the clue cards.

Nearly all the students were able to apply their chemistry knowledge during the escape game (92 % agreed/agreed mostly). This confirms that *Acid Base Global* was developed successfully taking the content of the curriculum into account. While students' general interest in chemistry did not increase through the escape room, over 77 % of the participants liked the escape room better than a regular chemistry class. Most students would participate in an educational escape room designed for chemistry education (80 % agreed/agreed mostly) again. The majority of the participants think that escape rooms should be used more often in the classroom (84 %) and would like to experience more escape rooms for different subjects and topics (89 %).

Conclusion

Educational escape rooms are a creative learning environment to learn and repeat knowledge and gain interdisciplinary skills. We recommend using our escape game *Acid Base Global* at the end of a teaching unit about acid and bases both in lower as well as upper secondary education (depending on the curriculum). The game can also be used to assess students' knowledge at the beginning of a lesson, like it was the case with one of the upper secondary trial groups. In general, escape rooms are well suited for a more student-centered and autonomous learning approach. Our escape room is perceived as interesting, fun and motivating by students and teachers alike. Indicators of success in the presented escape room seem to be group composition, collaboration, appropriate difficulty level, and prior experience with the game concept. A major difficulty for the learners is the hidden work instruction. Therefore, more scaffold hints should be provided. Nevertheless, the students especially liked the creative way of reviewing content knowledge through puzzles. In addition, escape games like *Acid Base Global* foster a wide range of interdisciplinary skills, most mentioned by the students are collaboration, logical thinking, communication and creativity. Furthermore, learners expressed multiple times that they would like to experience more educational escape games for different subject contents and would love to play another escape room in class again. Overall, escape rooms appear to be a promising innovative teaching method that is gaining popularity and should be researched further, especially due to the lack of empirical research, e.g. on students' motivation and the learning outcomes (Belova & Lathwesen, 2021).

Supplementary Material

All materials including clues, puzzles, hint cards and the teacher's guide, are available in German language under the following link: https://tinyurl.com/2p8ujx4t

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