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Interactive chemistry escape game as a tool of distance education: a case study of a pilot test from the first escape room

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The aim of this paper is to present an escape game which is the first part of a year-round, virtual, educational role-playing game built on the e-learning platform Moodle. The game is primarily focused on chemistry, although it has a great interdisciplinary overlap into physics, biology, and mathematics. The content of the game covers topics found in the chemistry curriculum at middle school and consists of a total of ten escape rooms. Each room—a separate escape game—is a self-contained unit, linked to the others by a storyline, and can be used as an educational tool even during long-term student absences, as was the case during the COVID-19 pandemic. The first room (escape game), as well as the entire year-long game, sets the mood and introduces elements of tension that reflect the story running throughout the game. The central concept is that of carbon being one of the most important elements on planet Earth. In this article, the first escape room (called Mixtures) is explained, as well as the whole overall structure of the game. The results from the pilot test conducted on 125 students are also presented. Students solved various types of tasks, and the testing showed that they performed best when describing chemical apparatus. Conversely, students were not very successful in tasks focused on chemical calculations. Teachers also shared their experiences with the escape game through a questionnaire. The teachers very positively evaluated the multidisciplinary nature of the escape game, especially the inclusion of mathematics.

KEYWORDS

high school, interdisciplinary, inquiry-based learning, eduLARP game, LMS Moodle, escape game

1 Introduction

1.1 Role playing, gamification and its benefits

The gamification brings many benefits for students and teachers—it makes lessons more attractive and fun, theories can be connected to real situations, students behave more spontaneously and are better motivated—this approach is generally more effective (Chans and Portuguez Castro, 2021). These benefits apply across the board, and chemistry

education is no exception. An example can be the use of gamification when solving homework (Villamor and Lapinid, 2022). Gamification can also help overcome the difficulties associated with the transition between high school and college (Brassinne et al., 2020). A specific area of chemistry where the gamification process is used is organic chemistry (Edwards et al., 2019; Fonseca et al., 2021; Hallal and Tlais, 2023). Another field of chemistry that has gained importance in recent years is green chemistry. In this context, games can be successfully used to teach environmental protection (Mellor et al., 2018; Trckova et al., 2023). A well-chosen game, relevant to the age of the players can improve both their knowledge as well as their skills. It allows the teacher to better understand the students' thoughts and decision-making processes, can be used as a tool for the nomination of talented students, and can serve to highlight the students' areas of interest. Moreover, the integration of game elements into the learning environment encourages students, develops creativity, and enables the easier achievement of set goals. It also supports constructive learning, problem-based learning, and experience-based learning, and increases the chances of group learning. It aids and develops the student's social and communicative abilities by, opening up space for discussion between students, supporting collaboration and communication, and improving the relationship between students and the teacher (Ding et al., 2018; Huang et al., 2019; Saleem et al., 2022; Václavíková, 2019).

In the educational process, the escape game form of Live Action Role Play (LARP) is currently the most widely used, because it is more motivating for students when the goal is clearly defined. They know what they have to do and after doing it there is a "reward" in the form of escaping the room or solving the mystery. Younger students in particular need to have fixed objectives with a large number of simple steps with the possibility of reaching the goal in a short time. It is therefore often better to use several shorter games, for example, a sequence of escape games which are ideally connected by one story or theme.

Games can be held either in person or online using a digital environment. Both forms have their advantages and disadvantages. When possible, it is beneficial to combine them (Dichev and Dicheva, 2017). Recently, driven primarily by the COVID-19 pandemic, escape games have increasingly shifted toward the online environment. Educational escape games that are created on a digital platform are often referred to as DEER (digital educational escape rooms). The benefits are playing from any place and time that suits the player.

1.2 Educational escape games—Summary of the current situation

Many strategies have been developed to teach chemistry based on the principles of escape play. The games frequently focus on a single one topic, such as the periodic table (Yayon et al., 2020), chemical bonding (Ang et al., 2020), or the process of soda ash production (Dietrich, 2018; Estudante and Dietrich, 2020). These games are often enriched by a mysterious story (Avargil et al., 2021), and they often take place in real laboratory (Dietrich, 2018; Ferreiro-González et al., 2019; Peleg et al., 2019; Clapson et al., 2020; Monnot et al., 2020), or in a virtual space (Vergne et al., 2020; Vergne et al., 2019; D'Angelo, 2020). Escape games can be designed for all levels of education, including universities (Ang et al., 2020; Watermeier and Salzameda, 2019; Aymard et al., 2021). Unfortunately, these games have a few shortcomings, such as a narrow focus or they lack any multidisciplinary relevance, as well as allowing limited opportunities for experimentation. Experimentation, both in and out of the laboratory, is a crucial element in teaching the natural sciences (Forbes et al., 2023; Lathwesen and Belova, 2021).

Another current trend in education is the introduction and use of inquiry-based science education (IBSE) (Raes et al., 2014; van Uum et al., 2016). Experimentation is a common and important part of this approach. If experimentation is part of an escape game, it usually takes place in the school laboratory. However, there are situations when students cannot get to the laboratory in person, and the alternative is in this case, to perform the experiment at home, or even virtually.

It is necessary to mention another disadvantage of the escape games currently offered by designers. Live-action games are typically designed for 3–4 h of play and, like digital games, are usually only playable once, since after playing, participants already know how the clues are hidden. This means the game has very limited replayability, and it is not interesting to play again. As a result, when used in education, the initial enthusiasm fades, and the educational benefits are not sustained. However, there are tools to mitigate this disadvantage and adapt the game for the whole class (Peleg et al., 2019).

The biggest disadvantage of the digital escape games is that they are not primarily designed as a distance education. They:

- are designed primarily for players (focus on emotional experience), not for teachers,
- do not contain parts to which the player/student would return if a part was misunderstood or failed, etc., it does not contain the possibility of analysis after the game itself,
- are practically separated from the educational process itself—they do not link informal education with formal one, they only complement it,
- do not offer the data for teacher about how successful the players are, what is the success rate of solving partial clues, etc.,
- are short, one-time, and the teacher who wants to use DEER in teaching, chooses a game for each thematic unit separately, each time with a different story, a different way of playing, notation, marking, etc.

The main objectives of the study can be summarized in these points:

- Develop a unique escape game that adheres to the principles we outline. The principles on which the game is based are outlined below. The escape game is presented in detail in Chapter 3 of this article.
- Conduct a preliminary evaluation of the first room of our escape game. The first round of feedback was collected from teachers, who evaluated the escape game based on various aspects described in detail in the Methodology section. The second round of feedback focused on the difficulty of the tasks. This feedback was gathered from students at several secondary schools who played the game.

1.3 Escape game as a tool of distance education

The educational escape game introduced in this article has the ambition of overcoming some of the shortcomings mentioned above by designing it as a tool of distance education. Primarily, it is designed as a year-round LARP game, consisting of 10 separate, self-enclosed escape games, each designed for one month of the academic year.

When creating our escape game, we were based on the following principles:

- Utilizing the Moodle learning management system in combination with "live action" components (experiential pedagogy). Observation and experimentation are essential for understanding natural sciences, and these practical skills are difficult to fully integrate into distance education. To address this, our game includes specific practical tasks that are based on the principles of inquiry-based science education (IBSE). These tasks encourage students to ask questions, formulate hypotheses, design experiments, and analyze data (Shamsudin et al., 2013; Moebius-Clune et al., 2011). This process helps students develop critical thinking skills like problem-solving, reasoning, and decision-making, which are crucial for success in science and beyond. While elements of IBSE have appeared in other authors' escape games (Ferreiro-González et al., 2019; Yayon et al., 2020), combining them with an online escape game is less common.
- Offer students a personalized learning environment, providing feedback on puzzle-solving success, tracking progress, and offering insights into game performance and point accumulation. Personalized learning allows students to advance at their own pace. High achievers can move quickly, while those who need additional support receive it. The game also teaches students essential skills such as goal-setting, time management, and independent research, providing instant feedback along the way. By meeting individual learning needs early, personalized learning helps prevent students from falling behind and bridges the gap between different levels of achievement.
- Sustain student motivation and excitement throughout the academic year. The game incorporates complex learning materials from different scientific disciplines, centered around a selected theme for each escape room. Our goal is to present each central theme from multiple perspectives so that students can see the connections between various scientific fields. The variety in task assignments enhances the game's attractiveness.
- Design the game to ensure that most of the time is spent on informal education. Informal education provides flexibility, allowing students to explore topics at their own pace and according to their interests. This approach fosters creativity and critical thinking by encouraging experiential learning outside traditional classroom settings. It often leads to greater engagement and knowledge retention, as students are more motivated when their learning relates to real-world contexts (Habig and Gupta, 2021).
- Implement interdisciplinary teaching across science subjects. Interdisciplinary education helps students develop critical thinking and collaborative skills, which are crucial for solving complex real-world problems. By combining different perspectives and approaches, students are better equipped to tackle complex questions (Ivanitskaya et al., 2002; Kim and Cho, 2015). Integrated teaching has a positive effect on students' motivation and their attitudes toward natural and technical sciences (Vennix et al., 2018). In our escape game, the primary discipline is chemistry, with strong connections to mathematics, physics, and biology. The game content is closely aligned with the secondary school curriculum and covers topics across these subjects. The teacher works with a single story throughout the year, while students engage with a unified environment that uses consistent notations, rules, and game mechanics.
- Provide teachers with visualized data on students' progress, with filtering options based on tasks, students, class performance, difficulty levels, and more. The LMS Moodle environment was chosen for this purpose, as it gives teachers a comprehensive overview of student activities. Additionally, it allows for the storage of all created learning materials, which remain available to students as they work through each escape room.

2 Methodology

2.1 Creating an escape game

The creation of the escape game itself consisted of the following steps:

- Selection of an interdisciplinary topic, e.g., Energy, Balance (see Figure 1).
- Creating the story for the entire escape game and its components.
- Construction of a concept map and a "library," which serves as a resource for solving tasks. The library also contains photos and videos of measurements and experiments.
- Developing individual tasks, with examples for the first room provided in the Supplementary material.
- Designing an IBSE task for the home environment and developing a method to verify it.
- Integrating all parts of the escape game into the LMS Moodle environment.
- Testing the game's functionality by the creators.

2.2 Pre-verification

The first version of the game is designed for secondary school students, covering relevant educational goals, learning outcomes, and curriculum. Additionally, in the Czech Republic, the high school curriculum revisits the same scientific themes

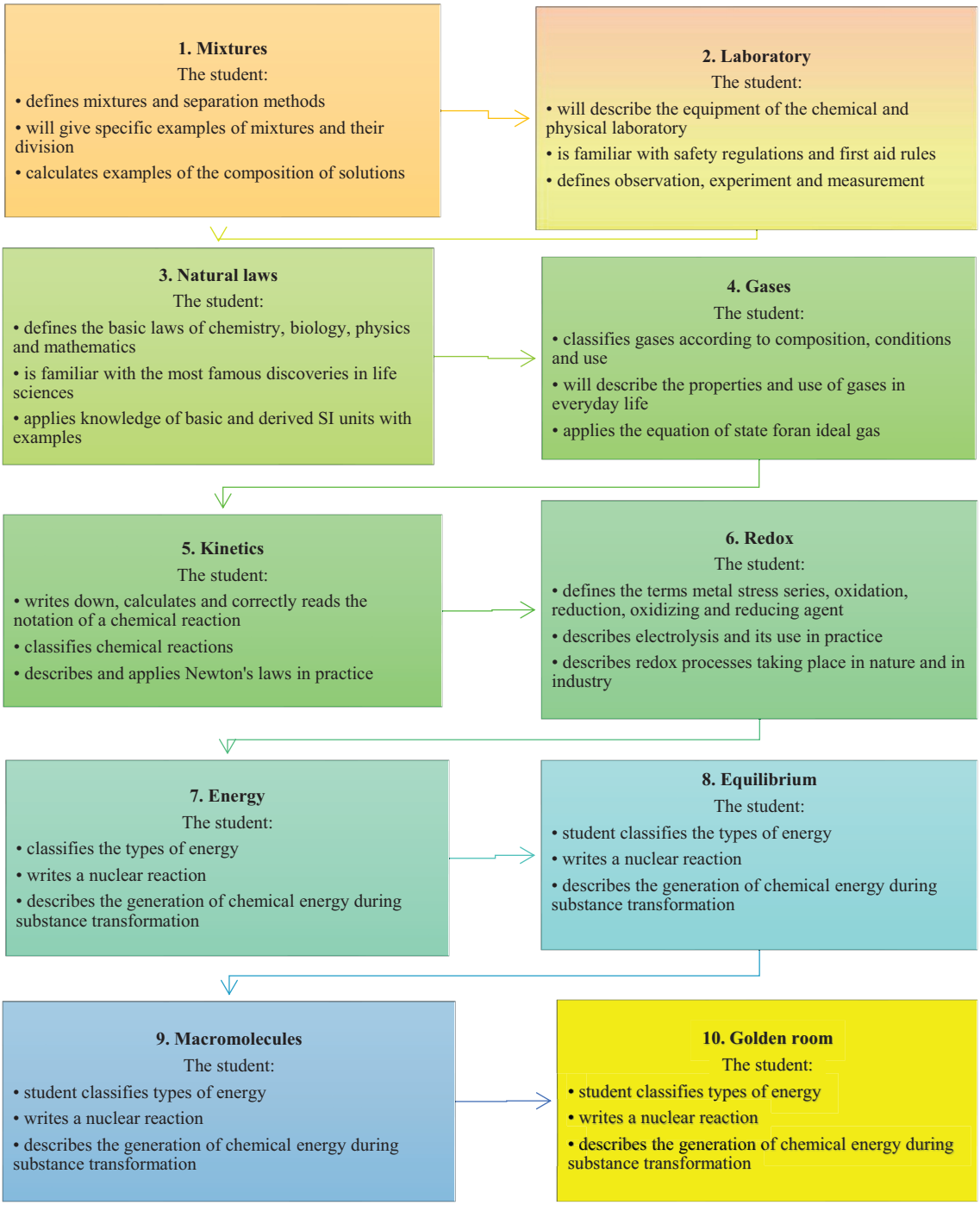

FIGURE 1
Themes of the individual rooms for the escape game and their learning objectives.

but explores them in greater depth. Therefore, the game can also be used for high school students. From the beginning, tasks are intentionally designed at varying levels, and each topic is supplemented with parts that go slightly beyond the standard scope of scientific subjects. This allows talented students or those with an interest in science to expand their knowledge. At the same time, minimum requirements for successful progress are set so that every middle school student can manage them.

We tested the difficulty of the tasks in the first room at seven schools, with 125 students participating. Middle school and junior high school students provided the first feedback, i.e., students aged 13–14.

Our university collaborates with many middle and high schools in the region. Teachers from these schools were invited to try the escape game. For interested teachers, an online course was prepared in LMS Moodle, explaining the game's design and how to navigate the LMS Moodle environment.

2.2.1 Data collection tools

2.2.1.1 Questionnaire for teachers

The first players of our escape game were teachers. Twelve teachers participated in the game and its evaluation. These teachers were given a questionnaire with the following questions:

1. What do you think of the storyline (professors, saving humanity, energy, secrets, etc.)?
2. How do you rate the LMS Moodle environment?
3. How easy was it for you to navigate the game (arrows, links, etc.)?
4. How do you evaluate the graphics? Are the images, photos, and videos appropriate?
5. The game focuses mainly on chemistry, but what do you think about the inclusion of mathematics, physics, and eventually biology?
6. Is the information in the library useful and sufficient?
7. Most books begin with a concept map. Do you consider it a useful tool?
8. Are crossword puzzles still effective for practicing the curriculum?
9. What do you think about fill-in-the-blank tasks and other text-based activities? Do they have a place in teaching?
10. How important do you think it is for students to be able to describe the filtration and distillation apparatus?
11. How would you evaluate the mathematical problems included in the "Mixtures" topic?
12. How do you assess the inclusion of the inquiry task, where students have to conduct their own "experiments"?

Teachers also had the opportunity to provide open-ended responses. In the results section, there are citations that document the assessment in more detail.

2.2.1.2 Creation of access to LMS Moodle and solution of tasks of the first room by students

The teachers could then, of course, pass information from testing and courses on to their students. Subsequently, each school sent a list of students and their email addresses. Each student received login credentials (a username and password). The same procedure was followed for the teachers. Students had one month to play the first room of the game. After this time, the students' results were evaluated.

2.2.2 Analysis

2.2.2.1 Teachers

We selected completed questionnaires from teachers and evaluated the average value for each question. The best rating is assigned a value of 1, the worst a value of 5. This system is in accordance with the classification in the Czech Republic, where 1 is the best grade and 5 is the worst. The results were processed in the form of a bar graph and sorted from the best rated question to the worst.

2.2.2.2 Students

We divided all tasks from the first escape room into groups according to the type of question: true/false, calculations, crosswords, making pairs from statements, labeling the apparatus. Each task was awarded a certain number of points according to its difficulty. If the student answered all the sub-questions in the task correctly, he received full points. If he answered half of the questions, his success rate was 50%. For each task, the percentage success rate for all 125 students was evaluated, as the average of individual results. The results were evaluated from the point of view of individual types of tasks and the results of middle school and high school students were also compared with each other.

3 Coaly stone: game design

The central theme of the overall game is carbon, which offers a huge range of applications in various areas such as (diamond, graphite, ash, fullerenes, graphene, activated carbon, coal, other fossil fuels, CO_2, carbonates, carbides, foam, adsorption, carbon filters, phase equilibrium, sequestration, extinguishing, solidification of mortar, carbon nanomaterials, carbon electrodes, hydrocarbons and their derivatives, photosynthesis, carbon footprint, dating, etc.). The choice of the central topic ensures that no area of chemistry will be neglected. Carbon and its compounds are relevant to all key areas of chemistry education. Furthermore, the topic of carbon and coal is relevant to our region and resonates in several areas, especially relating to energy and ecology. Our university and the city of Ostrava are located in the area of the so-called Silesian Basin. This is an area with significant historical coal mining.

3.1 Background to the mystery game

Following Lee Sheldon's three principles of storytelling (Sheldon, 2013): take me to a place I have never been, make me into someone I could never be, and let me do things I could never do, our story takes place in the near future. The Earth is plagued by an energy crisis. The place where the city of Ostrava once flourished has become part of the "Consortium," a financial and technological empire, currently the largest and most stable power on Earth. Artificial intelligence is ubiquitous—it has created its own community; which people have learned to use, and which even the empire tolerates in silence. Artificial intelligence has dominated the entire online space, thanks to its cybernetic brains it can seem distracted, sometimes incomprehensible and unsociable, but it offers services of all kinds with incredible speed. For unknown reasons, their currency is diamonds (a connection to the main topic—carbon).

One of the central characters is Professor Nialliv, the prestigious chemist and scientist. The players play the role of his student. A longtime colleague, Professor Nobrac, has turned to professor Nialliv for help. He left him a message "I have made an immense discovery that will change the world." Shortly after, he disappeared. Professor Nialliv also fears for his safety and has decided to secretly leave the country. He has contacted the player—as one of his best students asking for help.

Before his departure, Professor Nialliv managed to tell the student (player) that Professor Nobrac spent most of his time in his office, keeping careful records of everything in his secret diary. This is where the game itself begins–the player enters the first room–the professor's office.

3.2 The main parts of each room

3.2.1 Introductory photos with interactive elements

Each of the rooms is designed as a separate escape game and represents a different environment closely related to the story and educational topic. Some rooms will actually be in the form of a "room," others will be real places in our region that are somehow linked to carbon. These include the professor's office (the first escape room), a laboratory, a part of the map of Ostrava, a technical museum, a mine, a blast furnace, etc. From the central picture of the room, it is possible to enter all the other parts: the library, the virtual pawn shop, etc. The photos has interactive elements, thanks to which it is possible to explore the given room, view some elements located in it, and thus obtain partial information about the story and some clues. In order to explore some elements, it is necessary to have a sufficient number and kind of diamonds (they serve as currency throughout the game). Diamonds can be obtained in the virtual pawn shop by the player helping the AI create a database of story-related problem solutions. This forces the player to solve partial mathematical, chemical and physical problems, always related to the story.

3.2.2 Teaching phase—Library (chemistry, physics, mathematics and code books)

Inside each room (separate escape game), there is a teaching element which will contain the basic theoretical background for the correct solution for the tasks (virtual library). It consists of a text part, but also visual (or video) material, with photographs of laboratory glassware, instruments, and measurement records in the so-called virtual laboratory. Each room has one main theme. In terms of content, the topic is further divided into several sub-chapters. There are integrated elements of chemistry, physics, biology, and mathematics, which are not strictly divided according to school subject, but will be connected thematically. Moreover, there is a code book in each room, where a steganographic and simple cryptographic method will be presented and will need to be used somehow in the given room.

3.2.3 Solving phase—Virtual pawn shop

The next part of the room will focus on solving tasks, serving as preparation and support for the IBSE task. By solving the tasks, the player obtains various types of diamonds (natural, synthetic, pure, colored,...), which are necessary to make the subsequent clues available and, above all, to open the IBSE task. This task will be the most valuable, and will give the most points for its successful solution. A more detailed and specific description of the first room is given in one of the chapters below.

3.2.4 IBSE task

Each room also contains an IBSE task—a challenge in the form of a specific discovery experiment that the student has to conduct themselves. The IBSE task is designed in every room in such a way that it can also be carried out at home, using commonly available materials and in normal domestic conditions. Some experiments are designed for multi-day observations. The student has to scientifically document the experiments and draw conclusions based on their observations. The task is always related to the main theme of the room, but also directly to the storyline of the overarching story.

3.3 Moving through the game

The player is led sequentially through all nine rooms up to the golden one. The names of the individual rooms are shown in Figure 1. In each room, the player needs to successfully complete several activities to escape: find clues, collect enough diamonds by solving the tasks correctly (makes the IBSE task available to them), solve the IBSE task (this gives them some important information) and solve the escape from the room. Students can also earn black diamonds, when they do not solve a task correctly or if they need help solving a puzzle. Black diamonds do not count toward student scores, but serve as feedback for teachers to gauge student success. As students escape from the rooms, they gradually move a little closer to finding Professor Nobrac's immense discovery.

As mentioned, the game is designed to be used all year-round; there are a total of 10 rooms within the game—ten educational units (rooms). The first nine rooms are separate escape games and the last room, "the golden-one," will be "a reward," and the student will no longer have to solve any tasks. It will present information about news from the scientific world, about important scientists and discoveries that have changed the world. The main idea of the game is the essence of solving the global energy crisis, as can be seen from the initial entry into the game. During the sub-rooms, the student will gain knowledge of the methods for obtaining energy, its transformation, consumption (in connection with the carbon footprint), and the possibilities of how to save energy. In the golden room, students should be able to realize that energy is only transformed, so the only way out of the energy crisis is to adjust our lifestyle to avoid wasting energy.

4 The first room of the escape game

Individual parts of the escape game are described in detail in the Supplementary material appendix. All puzzles, tasks and calculation examples are listed here, including solutions.

4.1 What is needed to escape?

Firstly, we will briefly describe the passage through the escape game. The first room:

- At the beginning, it is good to familiarize yourself with the basic idea of the story, to understand that you need to solve tasks and get diamonds.
- Find the entrance to the pawn shop and solve tasks and puzzles. Get at least 50% of the points (diamonds).
- In the case that the students do not know what to do, they have a virtual library to help them.

FIGURE 2
Introductory photograph of the professor's office.

- Open the IBSE task assignment, perform the task practically and insert the results into the escape game environment.
- Solve the final code to open the door from the room.
- In the case that a hint is needed, they can enter the pawn shop and ask for help.

The players enter the first room with the information that they have to search for the professor's secret diary. Students find the diary on the table, but it is empty (it looks like nothing is written in it). In addition to the diary, there are many other elements in the room that the player can explore. Some of the items do not provide any necessary information, but gradually elaborate on the character of Professor Nobrac. There is always some information given with these items, but they are not necessarily the key to escape in a given room. However, some items communicate clues and direct players to how to advance the game. A picture of the first room (Figure 2) with the labeling of individual interactive items is provided in the Supplementary Figure 1.

In the first room, the concept of invisible ink is introduced.

The player has to find out that the diary is not empty, but it is written in invisible ink. Drinks on the table guide the player to this discovery. Or eventually the student can realize it themselves through the description of the steganography method in the code book (virtual library). The method for the preparation of drinks and their use as an invisible ink is the task of the IBSE. This task can only be opened with a certain number of points—diamonds. The player has to therefore enter the pawn shop and successfully complete some of the tasks (the limit is set at approximately half of all possible points).

The IBSE task then opens, and students prepare drinks according to the instructions, either at home or at school and test them as an invisible ink. Based on the chemical composition, the IBSE task then guides them to the method of revealing the secret script by heating it over a candle. The student then returns to the pawn shop and buys a candle and matches.

The text of the secret diary is revealed to the players. The text directs them to the lab (as the second escape room) where students find the next clues and tasks. The lab door appears as an active item but is locked. There is a stand with test tubes at the door, and one is missing. By reading an unsent email, the player has to find out that the missing test tube is the key to opening the door. Students has to also deduce, based on the order of elements in the test tubes, that the missing test tube should contain silicon (an element from Group 14 of the Periodic Table).

When the player works this out, they return to the pawn shop, buy the right test tube, and the door to the lab opens. The player successfully escapes the first room and is directed to the second escape room—the lab.

In the case that the player does not know what to do as their next step, the pawn shop offers "good advice"—basically a hint. For each hint used the player gets black points—small carbons. The number of small carbons will then show who managed to complete the game without help or how much "help" was needed.

Black points are also accumulated by purchasing unnecessary items in the pawn shop. For example, if player did not think

carefully about the test tube they needed and bought an empty test tube, not only would the door to the laboratory not open, but the player would be given one small carbon.

4.2 Library

In the first room, the topic of "Mixtures" is divided into: (a) characterization and categorization of mixtures, (b) methods of separation for the components of mixtures (separation), (c) solutions, (d) acids, bases, pH (proteolytic equilibria), and (e) mixtures in practice. Then there is the carbon theme, in this case foam (CO_2 in liquid form, Henry's law, solubility of gases), as one form of a mixture.

From the point of view of math, an introduction to logarithms is presented in the first room, the use of which is important for calculating the acidity and alkalinity of solutions (pH) and their percentage (computing the mass or volume fraction).

The first room of the escape game is focused on the topic of mixtures, their classification (homogeneous mixtures, colloidal solutions, heterogeneous mixtures) and their separation. On the first slide is a photograph of the professor's office (Figure 2), which contains links to the library, secret diary, motivational tasks and the IBSE task. There are several books available in the library, including; a chemistry book, one physics book, a math book and one cryptographic book, references to motivational tasks, the IBSE role and the key to the next room. In other words, if the student does not know how to solve the tasks, they can always look in the library, where they will find all the relevant information for the solution.

4.2.1 Chemistry

At the beginning of each chemistry book, an interactive spider concept map is inserted, in which the concepts and relationships between them are arranged. The concept map is used to reinforce the curriculum. The first diagram (Figure 3) shows the classification of substances according to various criteria, e.g., by occurrence in nature (chemically pure substances and mixtures), by origin (natural and synthetic) and by state (solid, liquid and gaseous). The second diagram (Supplementary Figure 3) graphically shows the classification of separation methods (filtration, sedimentation, crystallization, distillation, sublimation, chromatography and extraction). The third diagram (Supplementary Figure 4) describes the solution composition calculations. When clicking on a term in the concept map, an explanation of the term appears. The theory of the individual concepts includes examples from everyday life, photographs and videos. Examples of selected photographs are provided in the Supplementary Figure 5.

4.2.2 Physics

The theory described in the physics book is focused primarily on the characteristics of individual states. Phase equilibria and practical examples from life around us are also described here. A separate section focuses on water, its behavior and anomalies. Similar to the chemistry book, it begins with an interactive spider concept map and includes diagrams, graphs, and photographs.

4.2.3 Mathematics

The theoretical part contains firstly the explanation of logarithms as a tool for working with quantities that increase/decrease rapidly. It simply explains how to work with logarithms, presents the basic properties of logarithms and its connection to the pH calculation. Logarithms are not typically included in the secondary school curriculum, but were added to explore the potential for teaching this topic in the future. Secondly, there is an explanation of mass and volume fractions in connection with the absolute and relative expression of proportion and percentages and working with percentages.

All the theory is supplemented with specific examples.

4.2.4 Steganography and cryptography

The theoretical part contains a simple description of invisible ink as a steganographic method, interesting information from history, and examples of invisible inks that the student can create at home from commonly available ingredients.

4.3 Description of puzzles—The pawn shop

From the professor's office, there is a door leading to a virtual pawn shop. In it, the student faces various tasks, and for solving them they receive points in the form of diamonds. All subtasks are listed in the Supplementary material, including their solutions and learning objectives. A total of 13 micro-challenges are prepared in the first room. Each task is rated according to its difficulty with a certain number of diamonds. In total, a student can get 38 diamonds. To advance to the next step, however, they only need to collect 19 diamonds, i.e., a success rate of 50%. Once this value is reached, the IBSE assignment is made available to students. After solving them correctly, all that remains is to crack the last code to open the room (Figure 4).

In general, all tasks are related to the topic of the room and are related to game elements needed to escape the room. The tasks are of different types–computational, complementary, crossword puzzles (Supplementary Figures 6, 8), jigsaw puzzles, cloze passages, etc. Some tasks focused on the description of laboratory equipment, for example for filtration or distillation (Figure 5).

All tasks, although "mathematical, chemical, physical," are created within the language and context of the story. Each specific task pursues its own learning objectives, which are listed for each task in the Supplementary material. We believe that the motivational charge of playing a game can lead to a better and more permanent acquisition of chemical knowledge and skills. Students know in advance how many diamonds they can earn with the correct solution. Tasks are graded with pure diamonds (points) in combination with some colored diamonds (badges). The players can choose tasks according to their abilities, but student always needs a minimum set limit to get to the IBSE task and to escape the room (a given number of pure diamonds and a given number of colored diamonds). Colored diamonds—badges—are used to reward players for solving various tasks.

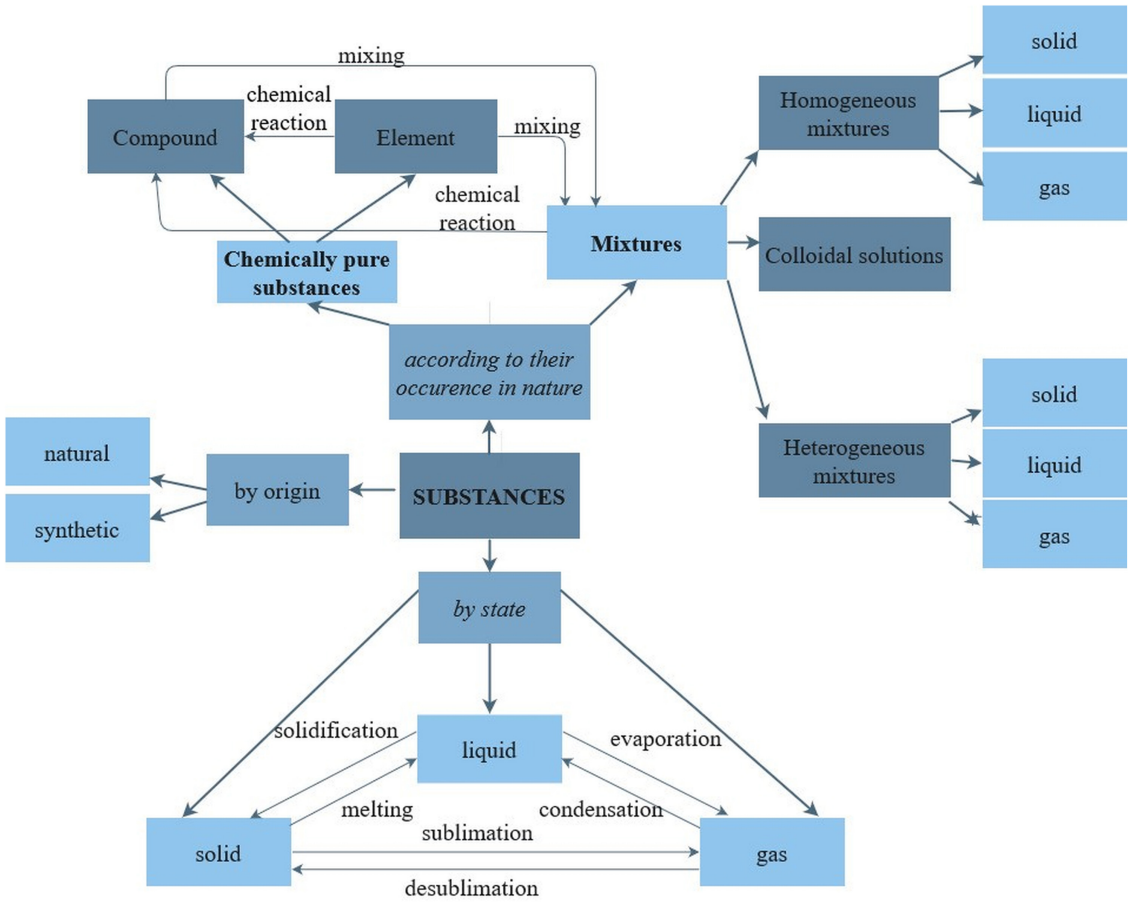

FIGURE 3
Spider concept map—classification of substances.

Mathematical tasks are focused on playing with logarithms, calculating the correct mixing of dried ink, solving the correct mixing of different mixtures that fit into the story. For example:

Professor Nobrac regularly mixed one of his secret inks exactly according to his proven recipe by dissolving 4 g of secret ingredient in 50 ml of water. Last time, however, he consumed only 60% of the prepared mixture, and unfortunately, he forgot the rest on the table in an open inkwell, so some of the water evaporated from it. When he returned, he found that 11.2 g of the mixture remained in the inkwell after the water had evaporated. Assume that the density of water is approximately 1000 $kg.m^{-3}$.

How much water does he have to add to the mixture in order to have the ink according to the original recipe? The four partial questions follow for answering the task (choose from multiple choice and true-false answer questions).

4.4 Description of the IBSE task

If the students get the required number of points (diamonds), the IBSE task is made available to them in the escape game. Its main educational goal is the development of practical skills. The inquiry task in the first room is focused on connecting theory with practice (for more information see Supplementary material). The student practically verifies the method of preparation, division of the mixture, calculation of the composition of the solution, writing the text with ink and revealing the secret font by heating the filter paper. By solving the inquiry task, the student strengthens their practical skills, learning competencies, and problem solving. The preparation of Mojito and Lemonade drink corresponds to the theme of the Mixed Room and the focus of the carbon escape game. The invisible ink contains the organic substance citric acid, which contains carbon. Citric acid decomposes the components of the paper and thus changes its surface. In the cellulose molecule, the chemical bond between the carbon is weakened. As heat is generated, the invisible ink substances are oxidized to carbon dioxide and at the same time the cellulose carbons affected by the ink are reduced to carbon at the oxidation number 0 and the text turns brown. Detailed information about the IBSE task is given in the Supplementary material.

5 Results

5.1 Escape game as a tool of distance education

An online escape game was prepared based on the principles we set at the beginning. Its main parts and the way it works

FIGURE 4
The final puzzle that opens the door. The bottle with which element is missing?

are described in this article and in the Supplementary material. The escape game takes place mostly in the online space. What fundamentally distinguishes it from similar escape games is that players are required to perform practical activities during the solution. These activities have the character of observations, measurements and experiments that students carry out in their home environment, and it is often necessary for them to visit selected localities in the vicinity and solve practical tasks there. As part of the story, students have to face the challenges and by solving them they get points that move them forward in the story. A benefit here is that the teacher can get the students to do the partial activities outside of school, and then get them to reflect on and analyze their experience through discussions when back in the school or classroom. The activities that are part of our escape game are intended primarily for teachers of chemistry and other science subjects. Both the game and the article have two main target groups, they are the already mentioned teachers, but also university students who are preparing to become teachers. One of our goals is to inspire and motivate these two groups.

5.2 Pre-verification

5.2.1 Teachers

12 teachers performed the first testing of the game and answered the twelve questions in the form of numerical values, which are presented in the Methodology chapter. Figure 6 shows the average values for individual questions. Questions are ranked from highest rated to lowest rated.

The best evaluation was achieved for questions 5, 7, 8, 9 and 10. Teachers evaluated well the part of the game in which the student solves the assigned tasks. They also appreciate the multidisciplinary aspect of the escape game. Information in the library and the use of concept maps are also among the positively evaluated parts of the educational program. The teachers evaluated the graphic side of the game on average (photos, videos, etc.), and they were also quite interested in the story that accompanies the escape game. The inclusion of the IBSE task among the mandatory elements of the game was evaluated with an average mark of 2.17.

Below are some comments from teachers:

"*The assignment of individual tasks is clear, the plot is understandable, great, wonderful, up-to-date.*"

"*The setting and story is perfect. It is quite real that artificial intelligence will greatly affect our lives in the future.*"

"*Connecting science subjects is a great idea! I believe it can lead to a deeper understanding of natural concepts.*"

"*IBSE task interesting, suitable for all students, easy to do at home, calculations are more difficult for elementary school students.*"

"*I really appreciate the placement of the concept map at the beginning of each room. It helps the students to get a comprehensive idea about the topic.*"

Teachers were quite critical of the LMS Moodle environment, average 2.42. Problems also appeared with the solution of mathematical problems, average grade 2.58. It is of some interest that the teachers who teach mathematics in addition to chemistry

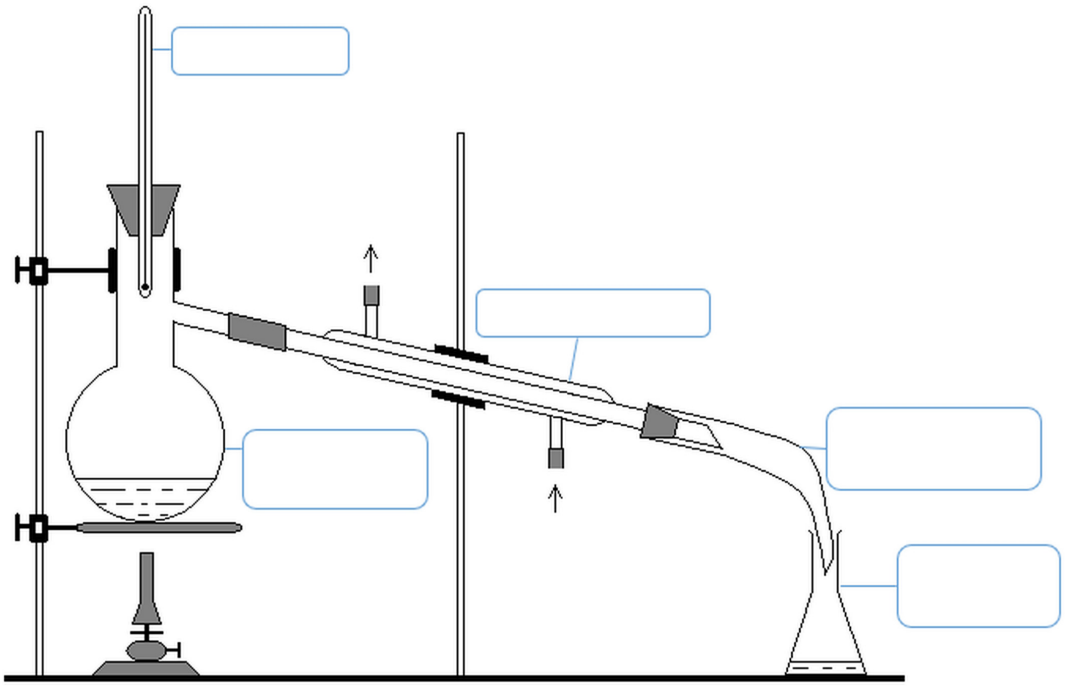

FIGURE 5
Distillation apparatus model. A task focused on the description of individual parts.

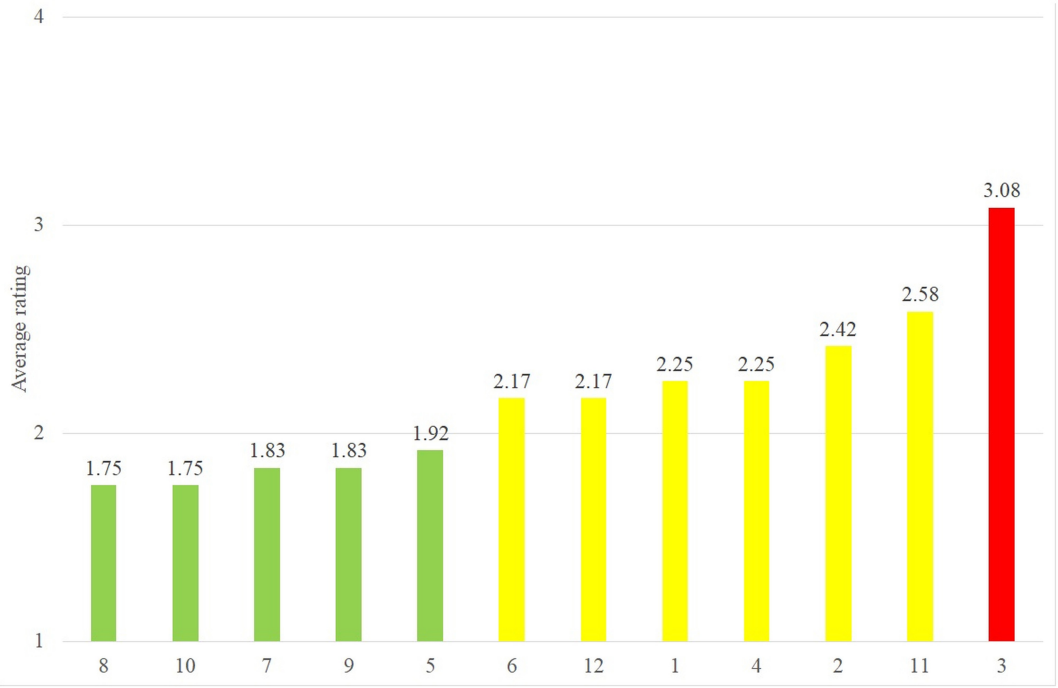

FIGURE 6
Average marks as shown by teachers' answers. On the horizontal axis are the question numbers as given above.

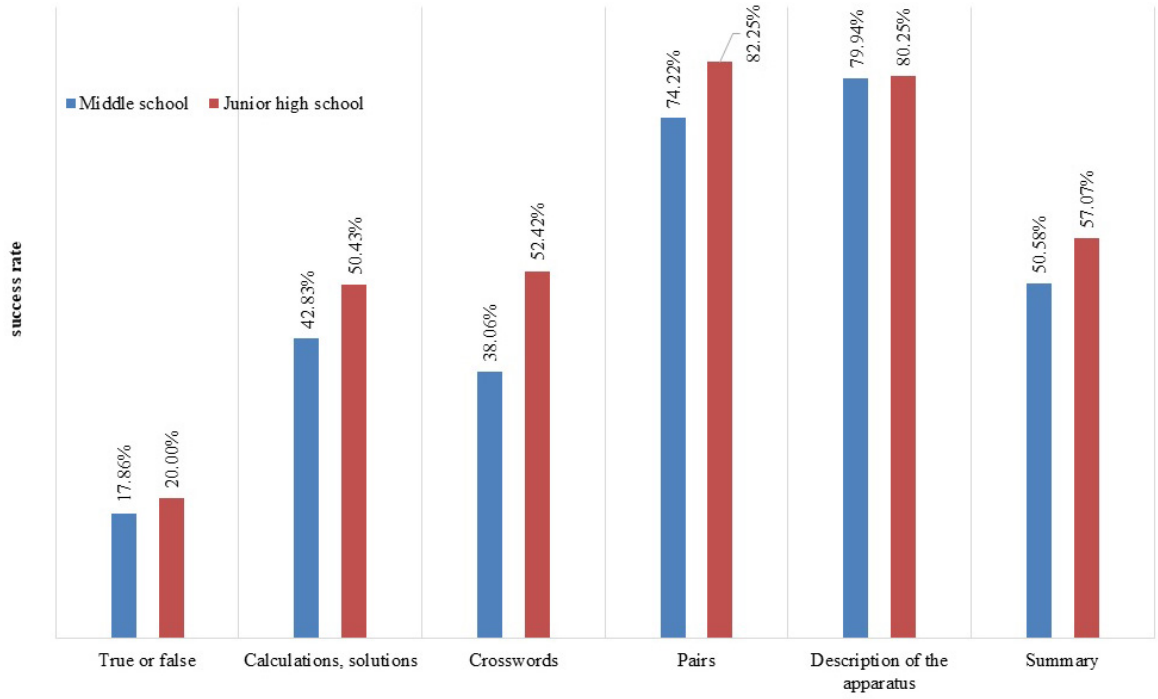

FIGURE 7
Percentage of success in solving individual types of tasks in the Mixture room.

evaluated this aspect rather positively. The worst rating was given to game control and orientation in the LMS Moodle environment.

Here are some examples of critical reviews of LMS Moodle:

"*The instructions for the first room are made completely confusing for the user: I see a play button there that does nothing.*"

"*Unclear environment in LMS Moodle–I miss the offer in the form of a drop-down window, information about successfully passing the rooms.*"

"*For a better understanding of the instructions and a more detailed insight into the story, the audio could be supplemented with a visual in the form of a video or animation.*"

5.2.2 Students

All the students who participated in the game testing had already discussed the topic "Mixtures" in school. The goal was to find out which type of tasks the students are most comfortable with and which they had the biggest problems with. We divided all tasks from the first escape room into groups according to the type of question: true/false, calculations (including work with logarithms), crosswords, making pairs from statements, labeling the apparatus (Supplementary Figures 7, **9**). For example, the calculation area included a total of four calculation examples with different assignments. Individual examples are given in the Supplementary material. Figure 7 shows the percentage of success for each task type.

The figure shows the success rate of solving individual types of tasks. The success rate is expressed as a percentage. This value represents the proportion of correct answers out of the total number of students who attempted the task. If a value of 20% is given, it means that only one fifth of the students solved the task correctly. The total score is the proportion of correct answers across all tasks. The overall success in solving tasks was very low and reached a value of approximately 54%. Two factors mainly contributed to this "failure." First of all, the tasks in which the students had to decide on the truth of the statement turned out to be the most problematic. The situation was similar for other tasks that worked with a continuous text. In international PISA comparisons, students from the Czech Republic rank average or below average in the category of reading literacy (OECD, 2022). The fact that the development of reading literacy needs to be given more focus in the 21st century also follows from the findings presented in the strategic document of the PISA organization (OECD, 2021). In the methodology materials for teachers, which will be prepared as instructions on how to work with the escape game, we will focus on the issue of working with the text. For these tasks, hyperlinks to the virtual library will also be inserted so that the student can find the correct solution more quickly. Secondly: students were not very successful in solving mathematical examples where the logarithms were used. This result is completely understandable, because logarithms were new for them. The logarithms were explained in detail in the library and we wanted to know to what extent the students would be willing to deal with a topic that is completely new and not absolutely necessary to progress in the game. It turned out, according to our expectations, that the students usually follow the easiest path—they are primarily interested in what is necessary to progress in the game. If a specific topic is the primary educational goal for us, it has to be closely connected to the story and a clue necessary to progress in the game. On the contrary, the tasks in which the students had to describe the distillation and filtration apparatus turned out very well. This can be considered a good trend; it is evident that their teachers allow enough practical time in laboratories in chemistry. The assignment

of concepts that are related to each other in pairs turned out very well. The chemical calculations were just above the 50% success rate. Here, too, it is necessary to pay more attention to giving more practice, in this area the students' abilities have been declining for a long time. When comparing results between middle school and high school students, it was evident that junior high school students performed better in most areas. This is not surprising, as junior high schools in the Czech Republic typically enroll gifted and motivated students. However, the difference was not significant, and in some tasks, the performance of both groups was comparable. Further research will be necessary to properly evaluate these results. This preliminary information, which we obtained from the students and their teachers, will be used for modifications to improve the first room of the Escape game, and we will also use the experience in the creation of other rooms.

6 Conclusion

Our experience so far in creating an escape game-based tutorial can be summarized by the following points:

- The LMS Moodle environment can be used to create an escape game especially as a tool of distance education. However, it requires the implementation of some applications and tools, as well as the need to program some activities, which may not be easy for some users. There were several reasons why we finally chose LMS Moodle as the environment for developing our escape game. (1) Availability and economic efficiency. Our university has a license for this platform, so there was no need to purchase anything else. (2) Easy access for game creators. All colleagues who participated in the development could very easily modify and develop the game. (3) Easy access for players. We were able to establish access to school students in a very simple way, regardless of geographic location. (4) Evaluation. LMS Moodle gives immediate feedback to players, but also to teachers, or to us game creators.
- Teachers positively evaluated the interdisciplinary character of the escape game educational program. The connection with mathematics seems particularly valuable. Compared to commercial computer games, the LMS Moodle environment is not so attractive; on the other hand, the inclusion of photos, videos and other multimedia content helped to narrow the gap and link to the curriculum. We have also added an audio track to the LMS Moodle environment to help students navigate the escape game.
- The biggest benefit of the LMS Moodle environment as a tool of distance education, is that the teacher has the opportunity to monitor the data on the students' achieved level. And not only the passage through the game itself, but also the degree of studied materials and the time span devoted to study. The teacher can work with the data according to his/her needs—by filtering according to groups of students or tasks. For example, it can monitor the success of partial challenges, i.e., the level of understanding of the relevant parts of the topic. If a task is not well solved by a larger number of students, the topic can be returned to during the lessons at school, or a set of similar tasks can be added to the bank of clues. From the data, it is possible to compare the success of classes with each other, the time required to solve tasks according to the difficulty of the example, or according to groups of students, etc.
- Interviews with teachers and students revealed that the benefits of using the LMS Moodle in teaching are also valid for our escape game. It is important for today's young generation that they can access the game and all the materials very easily through the internet. Students also used chats and other tools for interactive learning, communicating with their classmates and teachers. This fact also helps to build community. Feedback is no less important for students. Immediately after completing the task, the students knew whether they had completed it correctly or not. They had a repeated possibility of repair and also an easily available theoretical apparatus. Students also positively evaluated the possibility of choosing the order of tasks and the possibility of setting one's own pace of study and completing tasks.
- The story based on energy and ecological content is highly topical and makes students think about their attitude toward resources on our planet. The story itself and its characters were evaluated very positively in interviews with students and teachers.
- In the first room, which deals with the topic of Mixtures, the difficulty of some tasks was set very high and was demotivating for some students. Based on this feedback, we modified the tasks or added some information to the theoretical part of the game (library). We have also added learning objectives so that teachers know what each task is for.
- Our main goal for the coming period is to complete the whole story, the whole Escape game. The plan is to test it on the largest possible sample of students and then offer it free of charge to all schools in the Czech and Slovak Republics.

Data availability statement

The original contributions presented in this study are included in this article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

RM: Supervision, Writing – original draft. KT: Conceptualization, Formal analysis, Visualization, Writing – review and editing. ZV: Investigation, Methodology, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1405324/full#supplementary-material

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