Science4Exit Project: Experimental Escape Games With Digital Enrichment in an Extracurricular Learning Venue

David Ditter, Sarah Lukas, David Weiser and Isabel Rubner
University of Education Weingarten, Germany

ditter@ph-weingarten.de
lukas@ph-weingarten.de
david.weiser@ph-weingarten.de
isabel.rubner@ph-weingarten.de

Abstract: Exit games, escape games or escape rooms are innovative formats for teaching chemistry and for learning and applying scientific content. In the project "Science4Exit" experimental escape games with digital enrichment are developed, tested and evaluated. They will be carried out in the teaching and learning laboratory of chemistry at the University of Education in Weingarten. One of the project's goals is to increase pupil's motivation for science topics and interest in STEM subjects, as well as to improve the application of knowledge acquired in school. It also promotes 21st century skills (creativity, collaboration, communication, critical thinking and problem-solving) by embedding them in a game-based context. When playing escape games in the chemistry teaching and learning laboratory Ex³lab, experimental ways of knowing and solving are essential to reach the goal. As in classical or combinatorial puzzles, the result of an experiment is needed to unlock the next challenge. Escape games are partly digitally guided (e.g. by Actionbound, H5P) or digitally enriched with different technologies as needed (AR, explanatory videos, etc.). The Escape Games developed are used so that pupils can deal with scientific content in a playful and experimental way during a visit to the teaching and learning laboratory. They are supervised by student teachers as part of their studies. An escape game on energy supply and climate protection as well as building blocks for further developed escape games are presented below.

Keywords: Escape-room, Exit-game, Chemistry, STEM, Digitalization

1. Introduction

Escape games have grown in importance in recent years and have become a popular learning format. The playful approach of escape games, also known as gamification, has helped to increase pupils' interest in general topics (Tercanli, Martina and Ferreira Dias, 2021). The project Science4Exit uses this approach to increase pupils' interest in chemistry content through a game-based approach. Although game-based learning usually takes place in digital formats, this approach and this project emphasise the importance of combining hands-on experimentation and digital engagement with science content. The implementation is realized through escape games enriched with digital and experimental components.

In addition, the student teachers can gain practical experience in the context of supervising and accompanying the pupils and strengthen their competences in terms of teacher professionalisation. As the project progresses, the pupils themselves become active players and are involved in the design of further Escape Games.

In the following, a short introduction in game-based learning is given and specified by the application in natural science teaching. Subsequently, the project Science4Exit is presented as specific application example.

2. Gamification and Game-Based-Learning

According to Deterding et al. (2011), gamification embeds design elements from games in contexts that initially have a more serious background and are not playful This is often seen in everyday life through various intersections with gamification, such as when language learning apps use game elements to encourage users to continue learning content. Elements such as level systems, time pressure, narratives, avatars, points, teamwork, and competition are commonly cited (Reeves and Read, 2009). With respect to constructivist learning, the reverse – the "de-gamification" of a game – can be observed. It involves using elements, properties, or a whole game to deconstruct it and make it reusable for a new or different game with the purpose of creating a motivating learning environment. Game elements such as points or badges are used to increase the attractiveness of the activity and to motivate pupils towards goals that are not only for entertainment or commercial purposes. The term "gamification" initially originated in marketing, where the primary goal was to activate potential customers to buy a product or use an app (Kim *et al*., 2018; Le Lay *et al*., 2021). With regard to educational processes, the term was first used in 2002 (Sailer, 2016). As our society continuous to change through factors such as globalization and digitalization, the way we learn is also changing. Playful content has proven to be an attractive way to convey knowledge through this motivational approach and is increasingly being implemented in various fields of application. Due to the rapid development of digital and social media, there is a promising opportunity to extend gamification to the education sector (Aubeux *et al*., 2020; Goethe, 2019; Strahringer and Leyh, 2017; Kauffeld & Kettler, 2019; Kim *et al*., 2018; Sailer, 2016; Shute, Rahimi and Smith, 2019; Teclani, Martina & Ferreira Dias, 2021). The pedagogical approach of game-based learning uses games as a medium. These games contain systems of symbols and rules that enable pupils to interact with each other and with the game in order to achieve certain goals. Unlike mere play, rule-based games have their own game world that is distinct from everyday life. The use of narration and scenarios can stimulate the imagination of the players and enhance the immersive experience (Kettler and Kauffeld, 2019).

The process of playing occurs cyclical. In the first step, pupils receive academic input from teaching content. When applied to the topic of escape games, learners first receive preparatory material for the game in order to realize the input. This may include repetition of content covered in school or designed input, such as the processing of content through an explanatory video or worksheets that convey extracurricular subject matter. The characteristics of the game are then explained immediately before the start of the game. In the first sequence of the game, learners evaluate the input and act accordingly in the first challenges of the escape game. This may include the initial puzzle or experiment. If no action is taken due to missing information or prior knowledge, learners are supported appropriately by the tutors. Once the first challenge is completed, the players receive feedback from the game on the results of their actions, which then serves as the basis for the next action. This cycle continues until the escape game is successfully completed. In summary, game-based learning, as an active form of learning, is defined by solving puzzles and ultimately challenges (Schwan, 2006). It is important that tasks and problems reflect reality in order to promote learners' problem-solving skills and avoid the creation of inert knowledge. Therefore, the game scenario should be as close as possible to the real-world application scenarios of the subject matter in order to facilitate the retrieval of knowledge in real-world application situations (Kettler and Kauffeld, 2019). The concept of game-based learning offers a wide range of applications. These range from simple drill-and-practice games that serve to increase motivation in repetitive learning tasks, to the conveyance of complex theoretical relationships in simulation games. The use of digital technologies is not mandatory, but they are often a useful addition to the design and implementation of escape games.

3. Escape Games In The Context of the Natural Science Teaching and Learning Lab EX^3-LAB

Science teaching and learning labs typically constitute constructivist learning environments based on their objectives. Constructivist learning environments are defined to provide the possibility of an increased interactivity between the learner and the learning environment. The learner is asked to explore and interact with the environment and learning is hence a process or an activity and not a result (e.g., Anzai & Simon, 1979; Twomey & Perry, 1996).

Through these features, constructivist learning environments are thought to promote the so-called 4 Cs to a particular degree (see Figure 1; Brägger *et al*., 2021; González-Pérez and Ramírez-Montoya, 2022; Oelker, 2022):

- Critical thinking and problem solving
- Communication
- Collaboration
- Creativity and innovation

Figure 1: The 4K competences according to the 4K Model (own figure)

Science learning labs are run by departments of subject didactics at universities and not only cater for pupils but also involve teacher training students in the supervision and operation of the lab (Euler and Schüttler, 2020; Hempelmann and Kratzer, 2019). In the context of subject didactic courses, students are given the opportunity to design teaching materials for school classes and then test their skills by supervising and supporting pupils in the lab. This provides a protected space for the teacher training students to strengthen their skills while ensuring appropriate supervision of the pupils (Haupt *et al.*, 2013). Supervision in small learning groups, known as microteaching in academic teaching, ensures targeted supervision and intensive instruction of students. This specialized form of teaching and learning setting allows learners to improve their pedagogical skills by focusing on a narrowly defined topic area and concentrating on specific teaching methods such as instructing, observing, and supporting (Sorge et al., 2020). This form of learning is also beneficial and motivating for pupils as it provides an extracurricular, specialized form of subject-specific deepening in small, intensive learning groups.

In the context of the COVID-19 pandemic and digital transformation, student learning is changing both in school contexts and in individual out-of-school learning processes. Of particular note are the sales figures for puzzle and brain games, which are experiencing a significant increase in popularity (Statista, 2021). In the recent years, digital games and simulations have opened up for teaching and have since increasingly gained the interest of all actors participating in the education system (Selander *et al*., 2019) and have hence seen as a possibility to enrich teaching and learning laboratorys. Especially escape games seem to represent an emerging trend (Bell, 2018). Escape games bridge the gap between puzzle games and impressive scenarios in which the puzzles are located (Vergne, Simmons and Bowen, 2019). For example, in one of the escape games we have developed, pupils are faced with the task of having landed in space and having to find a safe way back to Earth. A key aspect of classic commercial escape rooms is that the participants are locked in as a small group of three to seven people and can only escape by solving the various puzzles found within (Dietrich, 2018). For safety reasons, this concept cannot be implemented analogously in the setting of a teaching and learning laboratory. As a result, escape games are developed that consider all of the desired facets that can be carried out within the requirements of the teaching and learning laboratory. When designing the puzzles, it is essential to tailor them to the target audience in order to prevent cognitive exhaustion and the associated failure in the room (Nicholson, 2016).

Multiperspectively, the model of the 4 Cs (see Figure 1) can be applied to the level of participants and creators of an escape game. In the game, players learn to think, learn, and act for themselves by solving puzzles and, in the chemical context, experiments (critical thinking and problem-solving). It is essential that learners engage constructively with the subject matter and solve problems as a team while not marginalizing personal, social, and communicative competencies (collaboration and communication). In the authentic learning situation, they are equally challenged to take risks and find creative solutions and ways to solve the puzzles (creativity and innovation) (Brägger *et al*., 2021). Similarly, the 4C model can be applied to students as creators. For example, in the seminar "Chemical Research Project," students cooperatively create building blocks for new escape games, pilot and evaluate them (cooperation). In the development process, they are in constant dialogue as a team (communication) to implement their respective topics or socially relevant themes reflected in the escape games (critical thinking). To avoid monotony in the game, creative and varied puzzles and exciting stories and ideas must also be implemented (creativity) (Banerji, Brott and Serwene., 2021).

Like commercial or recreational escape games, educational escape games combine practical and cognitive activities and thus appear particularly attractive as an opening form for learning settings because a free space for mistakes is provided during learning (Veldkamp *et al*., 2020). As a result, there is direct feedback for pupils' learning. This is achieved through a simple game loop of the escape games. In this loop, learners are given the challenge or puzzle/experiment to solve, and then receive a reward. These usually represent the next challenge or completion of the escape game (Wiemker, Elumir and Clare, 2015).

4. THE Project Science4Exit

In the project Science4Exit, gamification is applied in two ways: for the students who learn by creating escape games and for the pupils who use them in a traditional sense. The goal of the project is to develop, test, and evaluate experimental escape games with digital enhancements.

The gamified structure aims to promote interest in STEM subjects, especially in the field of Chemistry among pupils. In recent years, the number of pupils choosing chemistry-related study courses declined, while the demand for chemistry-related jobs has increased (Archer et al., 2022; Ulber, 2021). Among the reasons cited by Archer and colleagues (2022) are declining interest and low self-efficacy. By embedding classical topics of chemistry education in a playful manner, interest and self-efficacy can be increased. In the Science4Exit project, one of the ways to gain knowledge is through experimentation. The aim is to generate or confirm hypotheses about causal relationships while promoting 21st century skills. The framing is chosen in line with specific learning psychology concepts such as problem solving and research skills (Gut-Glanzmann and Mayer, 2018).

Therefore, pupils can actively and independently experiment and apply their knowledge to find a solution to a problem situation, supported by digital media such as augmented reality, virtual experiments, and explanatory videos. This form of competency-based learning allows pupils to deepen their knowledge in a practical way and understand complex relationships. These materials are developed, tested, and evaluated by students as part of their compulsory master's degree program in teaching (Rubner and Lukas, 2023). In addition, pupils are included in development and design work through the establishment of a research AG and thus actively participate in the project (Figure 2).

Figure 2: Integration of project participation among individual groups (own figure)

This enables a focus on their professionalization, in addition to the subject-specific competency acquisition of the pupils, which is an important aspect of the project. The supervision of pupils in the Ex^3-Lab is carried out by chemistry teacher training students who are prepared for supervision in the project as part of their education and receive continuous feedback. Moreover, the scientific supervision and mentoring of students promotes a sustainable exchange between theory and practice, as well as between universities and schools.

The focus of this project is the implementation of an educational escape games with an experimental orientation while it is digitally enriched. Various experiments are implemented in a narrative context. Just like in classical puzzles, combinatorial puzzles, or physical puzzles where for example the artefact has to be changed, the result of the experiment is needed to unlock the next challenge. An example of an experimental sequence is described below.

4.1 Application scenario of a chemical-experimental escape game

The pupils have crash-landed on an unknown planet with their spaceship and are trying to find a way back to Earth. They are standing in front of the command centre, which they need to enter to take control of the spaceship. However, the heavy door to the centre is locked. There is a keypad in front of the door, and as the captain of the ship has become somewhat forgetful in his old age, he had slid an iron plate with the numbers underneath the keypad. However, there are four digits on the plate and only two are needed to open the door. Through exploratory research, the pupils must carry out an experiment to find out how to identify the two correct numbers. Two containers are given, one labelled with a bluish solution (copper ion solution) and the other with a clear solution (distilled water). When the iron plate is dipped into the first and then into the second solution, two of the numbers disappear and the students can use the remaining two numbers as a code to access the command centre. The technical background to this is as follows: It is a cementation reaction that is triggered by immersing the iron plate in a sulphuric acid copper sulphate solution (bluish solution). In this reaction, the more noble copper (as copper ions in solution) precipitates on the less noble iron plate. Two of the digits were stamped on the plate with glycerine, which dissolves when immersed in the solution, as glycerine is water-soluble, so they are no longer visible. The remaining numbers were stamped on the plate with tallow, which is not water-soluble. Since copper cannot deposit on a plate stamped with tallow, the digits become visible (Figure 3). Finally, the students can enter the code (51), the door opens and the game continues.

Figure 3: The electrochemical deposition of copper on iron to visualize the solution numbers 5 and 1

In addition to physical objects, the materials and tools for the experiments and puzzles should be digitally enriched. This is achieved through augmented reality, virtual reality, videos, or apps, that engage learners in a targeted way and support their learning. For example, a fingerprint is made visible in an escape game using the iodine method (Rubner et al., 2018). In this experiment, a trace carrier with a latent fingerprint and some iodine crystals is placed in a vacuum syringe (syringe with a 3-way stopcock and an activated carbon filter, closed system) and by pulling back the plunger, a negative pressure is created in the reaction chamber. The negative pressure causes the crystalline iodine to sublimate, leaving it in a gaseous state. The non-polar iodine molecules are then deposited in the talc-like components of the fingerprint and the fingerprint becomes visible as a brown colour. The sublimation of the initially crystalline iodine is shown in detail in an animation (see Figure 4). As the animation progresses, the gaseous iodine attaches to the non-polar talc-like components of the fingerprint. The AR animation allows students to see the process of sublimation and incorporation of iodine visualised at the particle level (Krause and Eilks, 2020; Schneeweiß and Sieve, 2020; Thyssen, 2017; Wejner and Wilke, 2020).

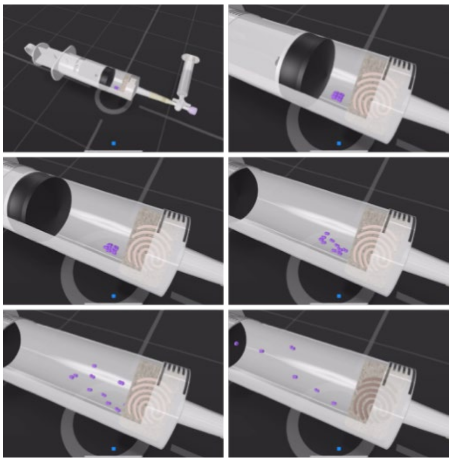

Figure 4: AR animation of sublimation and incorporation of iodine into a latent fingerprint

5. Research Within the Project

The growing importance of escape games in recent years and their potential for educational and innovation research has also been noted (Gentile, Allegra and Söbke, 2019). However, the topic is still poorly researched in the German-speaking region at present. An analysis of previously published articles on the topic of educational escape games (in year 2021), which selected informal and formal educational settings as a framework and were located within the tertiary and secondary education levels, identified 15 publications thus far. Nonetheless, gaps and large differences regarding the focus and research of escape games were found. With the consideration of common classifications of games/rooms, the field is expanding further (Lathwesen and Belova, 2021).

The results of the literature review show that research on escape games is primarily based on experience, observation, and feedback. Only occasionally is there a focus for example on pupils' or learners' interest or motivation. The project Science 4 Exit therefore aims in addition to provide further research and knowledge in this area.

The investigations in the project Science4Exit aim to assess the motivation of pupils and the associated effects on academic learning progress, as well as the cognitive effectiveness of the games. Furthermore, the study aims to investigate how participating in escape games affects the increase of interest and experimental self-efficacy. Finally, the study also focuses on the digital competencies acquired or reinforced through the games. Specifically, the study uses standardized questionnaires to collect data, which ensure high reliability and validity. Participants will be surveyed before and after each escape game to assess their starting level and changes regarding the variables being examined.

Measured constructs will be learning gain (pure knowledge and transfer to application), intrinsic motivation (e. g., Wilde et al., 2009), flow (e.g., Rheinberg, Vollmeyer & Engeser, 2003), self-efficacy in experimenting (e. g. Atzert et al., 2020; Dahmen et al., 2021) and interest in the subject. Also, the development of 21st century skills will be tackled in the research progress (Care, Griffin, & Wilson, 2018). The pre- and post-surveys enable a targeted evaluation of the learning progress and the effectiveness of the applied teaching and learning methods of the escape games. The collected data will be analysed using descriptive and statistical methods to ensure a detailed investigation of the response distribution. Inferential statistical procedures such as t-tests, analysis of variance, correlation analyses, and multiple linear regressions will also be conducted to explore the relationships between the various variables. The results of the study can contribute to improving the understanding of how escape games can be used to increase interest, motivation, and competencies of pupils in chemistry and other areas. Additionally, the results may also help to develop curricula and learning methods to provide pupils with a broader range of skills.

6. Conclusion and Future Directions

In an educational context, gamification offers the possibility of integrating playful elements into non-playful contexts. The use of gamification in teaching and learning contexts has grown in importance in recent years as it can increase learner motivation and engagement. It is important that games are perceived not only as entertainment but also as a learning environment. To achieve this, the learning content and the game-based narrative context need to be carefully selected and prepared to meet the needs and interests of the learners.

Escape games offer such an opportunity and are defined as interactive games in which players have to escape from a situation by solving puzzles and tasks. In an educational context, escape games can be used to deepen the scientific content learned in school in a playful and interactive way and to establish an application reference.

Today's generation of students increasingly uses digital media in their everyday lives, both for communication and entertainment.

For this reason, the use of experimental escape games with digital enhancements can help to increase motivation and interest in STEM subjects. Through digital enrichment, learning content can be delivered in an interactive and playful way.

The Science4Exit project is developing digitally enriched escape games to improve students' access to science content, particularly chemistry. The aim is to enable students to apply their knowledge and thus increase their interest in science. The digital enrichments make it possible to teach experiments not only in real life, but also digitally. In addition, the escape games use other digital elements such as augmented reality and explanatory videos to give students better access to the subject.

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