APPLICATION OF THE "ESCAPE ROOMS" IN STEM EDUCATION

Yanina Popova
Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Bulgaria
yanina.popova@iict.bas.bg

Elena Paunova-Hubenova
Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Bulgaria
elena.paunova@iict.bas.bg

Abstract

With the development of electronic and computer games, and also the virtual reality in the modern world, the role of games in the learning process is significantly expanding. Educational games have a number of positive effects, such as increasing student motivation, perceptual learning, and longer-term retention of knowledge. In recent years, the concept of escape rooms has gained popularity in pedagogical fields, especially in the context of STEM disciplines. They contain multiple puzzles, and the game structure is adapted to the specific needs of students and is linked to STEM content and specific competencies corresponding to the learning objectives. This overview study aims to analyze the following questions: What STEM mini puzzles are used most often? Which types of mini games and puzzles are most effective in different subjects? What skills do different puzzles develop? What technologies are used in the development of this type of games?

Keywords: *STEM Education; Game-based Learning; Escape Rooms.*

INTRODUCTION

Games are common among both humans and animals, as they allow children to learn about the surrounding world and themselves. They are important to people and can be found in different forms in all cultures and societies [1]. The effects of play on children's development are proven by a number of famous scientists in psychology and pedagogy, such as Maria Montessori and Jean Piaget [2]. According to Lev Vygotsky (1980), games provide opportunities for children to go through situations from real life for which they are not yet ready [3]. With the development of electronic and computer games and virtual reality nowadays, the role of games has begun to increase significantly. They are often used in the educational system in various forms, as they motivate learners and facilitate information retention [4]. They are used in different learning stages from preschool years to higher education, as well as in lifelong learning.

When reviewing the extensive literature on game-based learning (GBL) and gamification, it becomes clear that these tools can be used to achieve a variety of educational goals, such as promoting information retention, application of specific skills, motivation, teamwork, and argumentation [5]. To achieve a positive effect, some quality criteria are applied, supporting the creation of games that are not only fun but also contribute to achieving specific educational goals [6].

According to a number of studies, learning through games is gaining increasing popularity – some scholars even define it as one of the most discussed phenomena in the education field in recent years [7]. GBL is the integration of educational material into specially designed games, in which students acquire knowledge in a pleasant and imperceptible way [8]. Gamification is defined as the incorporation of game elements in order

to increase the motivation of students [9]. Game components are implemented specifically to achieve certain goals and solve specific problems [4].

The most commonly used components of gamification in educational contexts include storyline, game dynamics and mechanics, elements of collaboration, purposeful design, and a set of rules [4], [10]. Some of these elements are increasingly being used in digital gaming environments. However, effective gamification in education does not necessarily imply the inclusion of a strictly defined set of game elements, nor does the accumulation of a large number of them guarantee better educational results [11]. The main challenge for educators is to select the elements most appropriate to the respective context to build an integrated solution that facilitates the learning process [4].

Based on existing empirical evidence, studies such as [4], [6] propose a set of quality criteria that educational games should meet in order to be both motivating and pedagogically effective. Such games should be aligned with the learning content, have clearly formulated goals (e.g., progression or repetition), encourage active participation, be interactive and engaging, and include mechanisms for assessment and feedback. This allows learners to track and reflect on their progress in the learning process.

In recent years, the concept of educational games of the "escape rooms" type gain popularity in the pedagogical area, especially in the context of STEM (Science, Technology, Engineering, and Mathematics) disciplines. This trend is significantly noted in scientific publications and leading international conferences, and raises a number of key questions:

- For which STEM subjects are "escape rooms" most effective?
- What STEM mini puzzles are used in them?
- Which mini games and puzzles are most often used in different subjects?
- What skills do different puzzles develop?
- What types of technologies are used?

The present study aims to analyze existing sources on the research questions, assess whether the popularity of educational "escape rooms" represents a temporary phenomenon or continues to offer significant opportunities for development, and evaluate their potential as a pedagogical tool.

ESCAPE ROOMS

Everyone who plays a game steps out of their daily routine to immerse themselves in an imaginary world. This phenomenon is addressed in the concept of the "flow theory" [12]. Here, the state of "flow" is described as a state of complete absorption in a task that is both challenging and enjoyable. An example of a fully immersive recent trend in gaming are the so-called escape rooms, which gain popularity since around 2012 [13]. Escape rooms are physical adventure games in which players must work through various puzzles and tasks together to achieve a common goal within a set time limit [13]. Typically, the goal is to escape from one or more rooms. Alternatively, players must complete a specific task within the relevant story, such as solving a crime or finding hidden treasure. Before the game begins, the host informs the players about the rules, safety instructions, the general process, and the purpose of the escape room. If there is a background story, the moderator introduces the participants to it, for example, by reading an old diary entry. The door to the room is then locked, and the timer starts. Within the allotted time, players must use the objects they have found and decipher clues to solve the puzzles, which in turn provides them with progress in the game. During this time, the game leader acts only as an observer and can provide assistance to the group if necessary. The game ends when time runs out or the group has reached the goal.

In addition to physical escape rooms, due to their growing popularity and the needs of different application areas, other formats have been developed, including escape books, board games, augmented or virtual reality escape rooms, and digital games [14].

Different types of puzzles are an integral part of escape rooms. In such rooms, two types of puzzles are distinguished: mental and physical [15]. To solve the former, clues must be found, deciphered, and connected. This requires cognitive skills and logical thinking. The second type is physical puzzles or tasks in which real objects or parts of the room must be moved to find the solution. The two types of puzzles are often combined. Despite the variety of possible puzzles, three main structural components can be distinguished: a problem, a hidden solution, and a reward [15]. To receive the reward, players must first decipher the puzzle and complete the challenge. Often, the solution is hidden in the puzzle itself, and the reward may include new pieces of another puzzle, clues, or objects.

Educational escape rooms are an innovative form of learning that combines traditional pedagogical methods with interactive and practically oriented approaches. The game structure is adapted to the specific needs of the learners and can be linked to STEM content and specific competencies corresponding to the learning objectives. These rooms can be modified for all levels of the education system and can cover a wide range of disciplines [16]. The main function of educational escape rooms is to provide an opportunity to acquire new knowledge and skills through game interaction, as well as to consolidate, expand, and transfer already acquired knowledge. In addition to cognitive goals, social goals are also achieved - learners develop teamwork skills by improving their social interaction, including the acceptance of different points of view, self-assessment, and awareness of the consequences of their actions on the group [17].

Unlike traditional educational activities, the tasks in escape rooms are not presented through directly formulated instructions, but are implied and must be revealed through processing the information provided [13]. This, in turn, requires both students and teachers to go beyond the established pedagogical framework by creating a flexible educational environment. Adapting the escape concept to the school context involves considering the physical limitations of the learning space and the number of participants in the group [13]. In a school environment, 78.9% of educational escape formats are implemented in a single room, unlike commercial options that often include several spaces [14]. Therefore, the objects in the game scenario should be clearly distinguished (e.g., with visual markers) to be recognized by students [18].

The constraints associated with the available resources – spatial and financial – require that escape rooms be easy to reorganize and cost-effective. This implies that thematic decor and technical equipment should be implemented in a simple but functional way [19]. Despite the need for adaptations, the potential of educational escape rooms in the school context remains significant. They are perceived positively by both girls and boys, support different learning styles, and facilitate multidisciplinary learning, which is key for STEM education [13].

Furthermore, this method places students at the center of the learning process and encourages them to take responsibility for their own learning. The teacher serves as an observer of the process, providing assistance only when necessary, which opens opportunities for students to independently generate and implement strategies, solutions, and ideas [17]. This game-based approach not only engages students in non-traditional use of available knowledge and skills to solve challenges but also supports communication, collaboration, creative thinking, problem-solving skills, and critical thinking. Moreover, it has a positive impact on the motivation and proactive behavior of the participants [15].

APPLICATION OF ESCAPE ROOMS IN STEM EDUCATION

This paper presents a literature review on the application of escape rooms in STEM education. The following keywords were used in the study: "STEM education", "escape rooms", "educational games", "gamification", and "puzzle-based learning". The inclusion criteria are peer-reviewed articles published from 2020 to the present on escape rooms in the context of STEM education; the exclusion criteria are non-peer-reviewed publications and articles not related to STEM education. In this section, the above-mentioned research questions are addressed.

For which STEM subjects are "escape rooms" most effective?

Research in STEM education has shown that escape rooms are particularly effective in teaching physics, biology, chemistry, ecology, mathematics, and computer science. A recent meta-analysis [20] reported significant increases in achievement and engagement across STEM subjects. Another study provides a detailed review of the use of escape rooms in science education and highlights their particular effectiveness when using game-based approaches based on mobile applications [21]. Another analysis shows that integrating escape rooms into physics and mathematics curricula increases motivation and improves understanding and retention of the material, especially when social skills such as collaboration and inquiry-based learning are encouraged [22].

A Bulgarian study describes the use of escape rooms in physics and astronomy teaching as an effective way to engage students through practical tasks that require applying theoretical knowledge to real-world situations. This approach is consistent with the principles of constructivist pedagogy, where students construct their own understanding through interaction with the content [23]. The APOGEE platform provides another example of effectiveness across subjects, allowing the creation of adaptive 3D escape games for learning, including mini-puzzles and personalized educational elements [24].

What STEM mini puzzles are used in them?

In STEM escape rooms, mini puzzles play a key role in activating cognitive processes and connecting theory with practice. According to [20], mini puzzles most often include elements of logical thinking, arithmetic, time constraints, and group strategies, and solving each puzzle requires the application of scientific concepts. The literature describes tasks such as creating electrical circuits, reading mathematical or chemical formulas, combined with digital elements such as QR scanners and interactive platforms for monitoring progress [21]. The APOGEE platform automates the creation of mini puzzles that can be used to build escape room scenarios through 3D visualizations and script logic [25]. An example of an ecologically oriented game featuring a variety of mini-puzzles is shown in Figure 1. These include a question about opening a door to the next room, rolling balls on a map on the floor, letter soup, and searching for pairs of images [26].

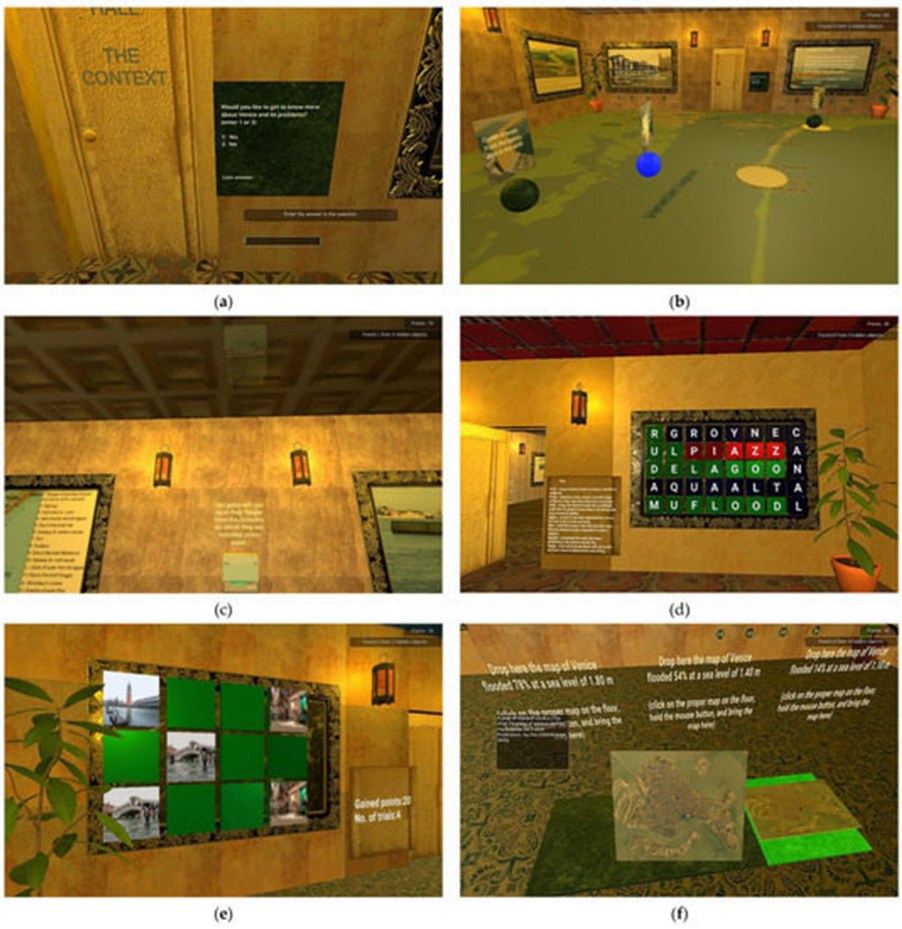

Fig. 1. Mini-puzzles in the ecological educational game "Let us save Venice" [26]

Which mini games and puzzles are most often used in different subjects?

The effectiveness of educational escape rooms depends not only on the game's design but also on the appropriate correspondence between the complexity, puzzle types, and subject content. Research shows that logical and numerical puzzles are most often used in mathematics, practical and experimental games are characteristic of physics and chemistry, and symbolic or language puzzles are used in computer science and engineering.

A 2021 analysis shows that mathematics most often uses equation-solving as puzzles, logical sequencing, and discovering relationships, often through digital platforms or analog tools such as locked boxes [20]. Physics and chemistry use interactive puzzles related to experiments – for example, arranging laboratory equipment in a certain sequence or analyzing simulation results [27].

Another study describes the use of virtual reality puzzles in biology that unlock scientific information or videos about specific processes, as well as environmental escape rooms that include real-time environmental data collection [28]. Another interesting approach has been proposed – the use of automated mini-puzzles in personalized escape games based on 3D virtual environments, which are applicable to technological and engineering disciplines [25].

What skills do different puzzles develop?

Mini puzzles in educational escape rooms convey knowledge and develop cognitive, social, and emotional skills, such as critical thinking, working under stress, and working in a team. Common outcomes of using escape rooms include increased engagement, autonomy in learning, and motivation, leading to a deeper understanding of the material [20]. Different types of puzzles develop different cognitive processes – logical tasks improve analytical thinking; puzzles related to performing a certain movement develop spatial thinking, and story-based riddles encourage creativity and empathy [28].

Participating in escape rooms significantly improves collaboration and communication skills, as success often depends on effective teamwork and information sharing [27]. According to another study, adaptive escape games based on game scenarios can increase flexibility in thinking and build interactive skills, especially in engineering and technology subjects [25].

What types of technologies are used?

In recent years, there has been a clear trend toward the use of digital technologies in STEM educational escape rooms. Recent research shows that the application of modern tools, including virtual escape rooms, increases engagement and enables personalization of the learning process [20]. A distinction is made between classic (analog) escape rooms and hybrid or fully digital formats, stating that digital environments allow for greater flexibility, accessibility, and adaptability [27].

Studies have demonstrated the successful use of virtual reality (VR) escape rooms, with an impact on student outcomes and interest in the learning material [28], [29]. Similarly, the Bulgarian platform APOGEE [25] applies interactive 3D technologies and gamified interfaces, which facilitate the creation of adaptive escape rooms for various STEM disciplines. However, the potential of real (physical) puzzles should not be underestimated; according to [21], they are preferred in primary and secondary grades because they promote tactile learning, team dynamics, and sensory perception in the classroom.

CONCLUSION

The results show that educational escape rooms effectively combine game mechanisms with a pedagogical purpose. The impact on student motivation, learning through practice, and the development of transversal skills is particularly strong. Digitalization offers new opportunities, but real puzzles remain important. It is crucial to adapt the game design to the specific subject content.

Escape rooms are most effective for teaching physics, mathematics, computer science, chemistry, and ecology, providing an engaging, interactive, and interdisciplinary environment that promotes learning, but also stimulates the development of interdisciplinary skills such as critical thinking, collaboration, and strategic planning. In STEM education through escape rooms, mini-puzzles support cognitive activity and the application of theory in practice. The most common types of mini puzzles include: logic tasks, code cryptograms, sequential puzzles, model assembly, mathematical equations, and realistic simulations. The effectiveness of educational escape rooms depends on the correspondence between the design, the complexity of the puzzles, and the subject content. Most often, logical and numerical puzzles are used in mathematics, experimental tasks in physics and chemistry, and symbolic or language puzzles in computer science and engineering. Mini puzzles in educational escape

rooms not only convey educational content but also actively develop important cognitive, social, and emotional skills in students. Among the most commonly developed skills are: critical thinking, problem solving, teamwork, decision-making under pressure, creativity, and digital literacy when technological elements are used. In recent years, digital technologies have been increasingly applied in STEM "escape" rooms. Depending on the goals of the game, the audience, and the subject, both real (physical) tools and puzzles are used, as well as high-tech solutions such as virtual reality (VR), augmented reality (AR), QR codes, simulations, embedded sensors, and online platforms for game control.

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