TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special III, Jully, 2024

INTEGRATING ESCAPE ROOM GAMES IN TEACHING OPERATIONAL RESEARCH CONCEPTS

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Abstract: *Escape rooms have gained popularity as engaging and immersive learning experiences, but their potential to teach Operations Research (OR) concepts remains largely unexplored. This article proposes a framework for using escape rooms as an innovative teaching tool in the field of OR at the Faculty of Management in Production and Transportation of the Politehnica University of Timisoara. The framework is designed to enhance students' understanding of OR methodologies, problem-solving skills, teamwork, and critical thinking abilities. Often students face a lot of challenges when facing algorithms and methods and that is why this paper aim to provide a structured and interactive learning environment that promotes active participation and knowledge retention. This article contributes to the growing body of literature on experiential learning methods and provides educators with practical insights for implementing escape rooms in the OR curriculum.*

Key words: *educational escape games, experiential learning, operations research, serious gaming, game-based learning.*

1. INTRODUCTION

Escape rooms have emerged as a popular educational tool, providing interactive learning experiences in various disciplines. Educational Escape Rooms acquired attention for their ability to elevate learners' motivation, cultivate crucial 21st century skills, and foster improved knowledge acquisition [10]. Hence, there is a shift from traditional education to the adoption of innovative approaches that harness sustained motivation and engagement in the classroom. One such approach is the integration of educational content within a game-based context, which has been widely reported to be effective in promoting high levels of motivation and engagement among learners [9]. Although it may be assumed that Escape Rooms are primarily suitable for younger learners, this gamified experience is considered an appealing attraction for adults as well [14].

In [17] the following definition is given: *"Escape rooms are live-action team-based games in which players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to achieve a specific goal (usually escape from the room) in a limited amount of time"*. Participants must complete all tasks to solve the challenge and "escape" from the proposed scenario.

According to [9], when this concept is extended to education, an escape room represents an instructional approach that engages learners in collaborative and playful activities specifically designed to facilitate the acquisition of domain knowledge and the development of skills. In an educational escape room, participants work together to achieve a specific goal, such as escaping from a physical or virtual room, unraveling a mystery, locating a hidden item, avoiding a disaster, or breaking a vault. Puzzles and challenges presented in an educational escape room are carefully designed to align with clear learning objectives of a certain discipline, and participants must solve them within a limited time frame, adding an element of time pressure to the experience.

Modern escape rooms can be divided into four generations, based on their use of certain technologies [21]. This classification refers to

escape rooms developed since the late 2000s until today, also considering the possible evolution of this field in the future. The first generation starting in the late 2000s until the early 2010s, made use of technology to a very small extent and is characterized using simple locked boxes, magnets or padlocks. The second generation of escape rooms started in the early 2010s and it goes on until now, being marked by the growing popularity of escape games between game players. These rooms have started to be increasingly automated, being also characterized by the presence of a "game master" as a non-character in the game, but who makes sure that everything goes according to the plan. The third generation of escape rooms starting from the mid 2010s and until now use even more sensors and technology that automatically enables certain elements for the players. The fourth generation of escape rooms, considered to be the next step in the field of escape rooms, refers to fully automated games, characterized by adaptable strategies used in video games and making use of augmented and virtual reality.

According to [14] most of the educational escape rooms are from the first and second generation, involving a lot of work on the part of the teacher to set up the game and to be available for any intervention, to offer guidance, clues, or other forms of support. This can often be an obstacle for teachers to approach such a game-based method in their teaching process. The third or fourth generation of escape rooms facilitate automatic student monitoring and allows students to benefit from adaptive strategies and individualized learning experiences. At the same time [14] claims that the third and fourth generation of escape rooms also come with challenges for educators from the lack of knowledge or resources in developing high-tech solutions for escape room games. This brings us to the fact that teachers need training and support for information and communication technologies solutions to be able to create and use escape rooms and game-based learning when working with students.

As mentioned in [22], in literature all activities that take place in an escape room are called puzzles and are categorized as follows:

- Cognitive puzzles: puzzles require participants to use logical thinking, deduction, and inference to solve problems;
- Physical puzzles: puzzles that involve tangible objects or components that participants manipulate or interact with to find a solution. Unlike digital or paper-based puzzles, physical puzzles engage participants through hands-on exploration and manipulation of physical elements.
- Meta-puzzles: puzzles that require participants to solve the previous interconnected puzzles from the game or gather information from different puzzles to find a final solution or answer. It is considered to be a higher-level puzzle that ties together various elements or clues from the other puzzles within the escape room.

This paper provides a framework for teachers to develop game-based activities in the field of Operations Research. It is organized as follows. First a review of the existing literature on game-based learning and educational escape rooms is presented. Second, the use of these game-based approaches is discussed from the perspective of their use in Operations Research. Next, a linear approach of an escape room game is proposed to be used or adapted on the different themes of the field of OR and in the end, the author discussed the conclusions and limitations of the hypotheses supported by this paper. The paper has to offer the answers for the following questions: description of the problem, what is done by other people, what the authors did, what is new, what is my contribution?

2. GAME-BASED LEARNING: A LITERATURE REVIEW

Learning is an engaging and dynamic process that requires intrinsic motivation to initiate and sustain progress. In the context of Operations Research (OR), traditional instructional methods may be perceived as dull and ineffective by some students. This lack of motivation becomes particularly apparent when students lack prior mathematical knowledge, making it difficult for

them to grasp the objectives of the learning activities. Additionally, conventional training approaches that rely on written manuals and verbal instructions prove inadequate for students to familiarize themselves with the algorithms and methods used in the field of OR. Considering these challenges, it becomes imperative to explore innovative approaches that can address the limitations of traditional training methods, enhance motivation, and provide meaningful hands-on experiences within the constraints of the previous level of training in mathematics. Many researchers have already developed several models and frameworks to analyze the opportunities and limitations of using games in education, highlighting methods to structure these games in a way that supports effective learning [4]. In the review of the literature on gamification in education [24], quote that there is an increasing interest in gamification in education. There are many disciplines where gamification was applied, including math, manufacturing [3], health, computer science, or chemistry.

Gamification goes beyond the fundamental principles of active learning methodologies and incorporates elements of game mechanics to enhance the overall learning experience, foster higher levels of engagement, and improve performance. Research studies, such as those conducted by [2] and [5], have demonstrated the potential of gamification to positively impact various aspects of the learning process. Gamification not only encourages active engagement, but also enhances knowledge retention and promotes critical thinking and problem-solving skills among learners. Furthermore, the implementation of gamification has the potential to cause a positive psychological and behavioral shift in learners [12]. It can significantly impact both intrinsic and extrinsic motivations [7], [19] which play a crucial role in educational achievement [23].

Teaching engineers' theoretical concepts and technical skills is relatively straightforward, but fostering their creative application in design activities presents a significant challenge. Encouraging engineers to use these tools and techniques in an innovative way, requires alternative approaches. An effective method is to assign problems that are not conventionally perceived as suitable candidates for established solution methodologies. In this regard, incorporating games into engineering education can be particularly valuable for fostering creativity in design [8]. An area where this is often observed is in the teaching of mathematical programming techniques to industrial engineers. By presenting students with game-based scenarios that require mathematical programming solutions, students are challenged to think creatively and apply their knowledge in unique ways. This approach proves to be engaging and enjoyable for students as they can easily visualize the problem formulations and verify their solutions using simple games. Furthermore, the skills acquired by formulating solutions to game-based scenarios using mathematical programming techniques can be readily transferred to real-world engineering problems. Although further research is required in this area, it is believed that the formulation skills gained have significant applicability and can enhance engineers' ability to tackle more complex and realistic engineering challenges. The combination of creative thinking, problem-solving, and the inherent enjoyment of game-based learning makes this approach a promising path to foster innovation and skill development in engineering education.

There is not much current literature of using games or puzzles for educational purposes in the field of OR and most of the literature related to teaching mathematical modelling, comes from the field of computer science [16]. According to [20], games and puzzles for OR courses are primarily used because mathematics plays a crucial role in OR. These interactive and problem-solving activities provide rich material to teach OR concepts. Combinatorial optimization, a central area of OR, finds its relevance in various games, as it can be effectively formulated as combinatorial optimization problems. By exploring these game scenarios, students can gain a deeper understanding of the underlying principles and techniques used in the OR.

3. EDUCATIONAL ESCAPE ROOM FRAMEWORK

Escape games offer a problem-based approach to introduce different subjects, engaging students in active learning. By presenting students with challenges that require investigation and experimentation to find solutions, escape games encourage students to think outside the box, fostering a dynamic and engaging learning experience. Educational escape rooms are a type of learning game that integrates educational concepts into engaging puzzle solving experiences. Although it is a relatively new concept, educational escape rooms are gaining popularity and expanding in their application. They have been successfully implemented in various disciplines, and studies and reports have consistently highlighted the positive experiences of learners, including high levels of enjoyment, teamwork, and engagement during these educational escape room activities [18].

The first theoretical framework of educational escape game (EED) was EscapeED, providing a methodology to create interactive game solutions for learning in a higher education context [6]. The six main areas of the EscapeED prototype are: Participants, Objectives, Theme, Puzzles, Equipment, and Evaluation. To develop an educational version of the escape room, it was necessary to break down each of the six areas into specific segments. These segments were carefully identified and incorporated into the design process to ensure that the educational objectives were effectively addressed. Escape games have also gained popularity among computer programming educators, as demonstrated by the work of [11].

In their study, an escape game was developed using the Thymio educational robot to introduce young learners to the world of robotic programming. The game involved a series of challenges in which participants had to unlock bags or suitcases secured with number locks and chains. By successfully completing these tasks, the students obtained the information necessary to use a visual programming language and control the movements of the Thymio robot.

The escape game format provided an immersive and interactive learning experience, allowing participants to actively engage with the programming concepts in a hands-on manner. This approach not only made the learning process enjoyable and engaging but also provided learners with practical experience in using programming languages and interacting with robotic devices. Another example of using educational escape rooms but for mathematics in secondary school, is presented in [1].

The Escape Room design process was a collaborative effort between mathematics teachers and researchers specialized in this field. The room was equipped with three computers and a tablet, providing students with access to online resources to help them solve codes and advance through the game.

The room contained a total of five puzzles, all of which were based on mathematics problems that required problem solving skills to resolve. The results suggest that the incorporation of escape rooms in mathematics education positively impacts student achievement, reduces anxiety, increases motivation, and promotes autonomy. It is important to address negative attitudes toward mathematics learning, especially in relation to autonomy and motivation. Escape rooms have the potential to surpass traditional approaches in mathematics by actively engaging students and fostering interaction as integral components of the teaching and learning process.

In the field of Operations Research current literature is almost non-existent, [8] provide the only existing proposals of games and puzzles to teach OR. “The Cracker Barrel Peg Board Game” is an interesting game for teaching engineering design using OR. “Peg Solitaire Problem” was used to introduce students to the formulation and solution of large-scale optimization problems and time-based decision variables. Games cannot be used exclusively to teach the desired techniques. Games, such as the board puzzles discussed in [8] can help students learn creative formulation and solution techniques and their understanding of the foundations of solution techniques in more realistic settings but cannot be exclusively used to teach OR concepts. Educational escape rooms can help students gain knowledge and understand certain topics in an organized context. Based on Bloom’s Taxonomy, Figure 1 provides an example of how escape games can include all levels of cognitive activities, starting

from acquiring basic knowledge and comprehension of the subject matter, and gradually advancing to applying, analyzing, synthesizing, and evaluating information within the context of the game.

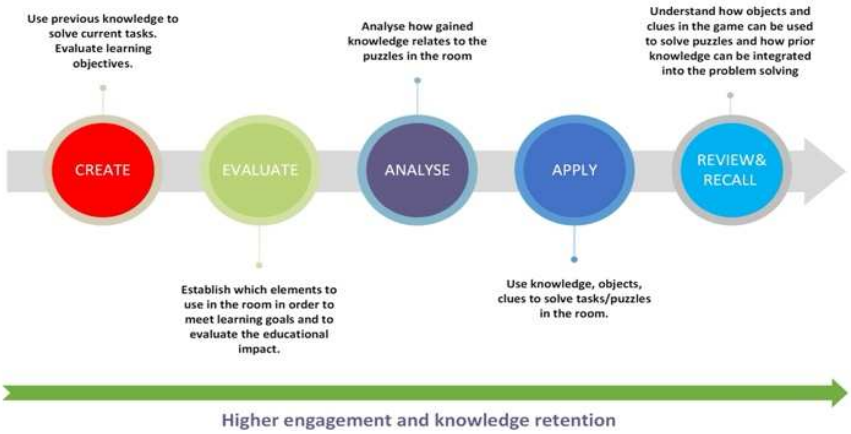

Fig. 1. EERs analysis within the revised Bloom's Taxonomy framework (adapted from [10]).

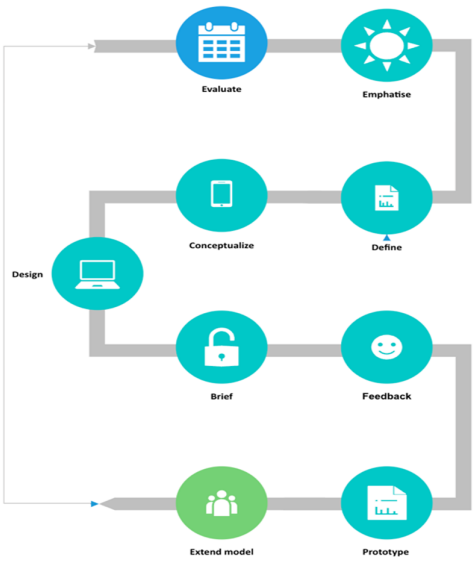

Fig. 2. Educational escape room framework (adapted from [10]).

This paper presents an extension of the educational escape room concept by introducing an educational escape room specifically designed for teaching Operations Research. Operations Research is a multidisciplinary field that studies the application of advanced analytical methods to help make better decisions in complex problems related to the operation and management of systems. It includes a diverse range of topics, including optimization problems, decision analysis, games theory or queuing theory.

4. METHODOLOGY

Although there are several framework approaches in the scientific literature, [10] state that there is often a lack of emphasis on evaluating the quality and effectiveness of the frameworks themselves in terms of their usability and usefulness. Instead, the focus tends to be on assessing the impact on learning by examining a single prototype escape game developed within the framework. To overcome this shortcoming, they propose Room2Educ8, a user-centered, conceptual framework for EER design that can be adapted to any subject and escape room type. Room2Educ8 is a versatile conceptual framework that can be customized to suit various subjects, learning outcomes, and class sizes. By adjusting escape room type, puzzles, and narrative, educators can easily adapt the framework to their specific needs. Provides comprehensive guidance for creating engaging and effective EER experiences. The framework has undergone iterative development since 2018, incorporating pilot testing and continuous refinements of its individual elements. Based on Room2Educ8, in Figure 2 we present an adapted process of developing an escape room prototype for the OR discipline.

The first step in creating the room is the "Empathise" phase, where all data are collected. These data can be obtained through research in the academic literature from interviews,

observations, surveys, focus groups, or other types of data collection. In this paper, data was collected from the academic literature and best practices used also for other disciplines [1], [6], [9], [13] and [14]. The OR escape room puzzles have been designed to be completed in a linear format, where one puzzle needs to be completed to proceed to the next puzzle. Linear pathways offer participants a clearer understanding, ensuring a smoother flow of the story and allowing for timed and paced gameplay. As a result, less guidance is required, and monitoring progression becomes easier The OR escape room game is addressed to second year students from the Faculty of Management in Production and Transportation of the Politehnica University of Timisoara. Operational Research is a mandatory subject of study, the course takes place weekly over a period of 14 weeks and provides the basis for other courses in the following years.

The second step of the framework from Fig. 2, is "Define", and focuses on setting learning objectives, problem statement, possible restrictions, group size, game length and possible restrictions in the curriculum [10].

The main learning objectives for the OR course are presented as follows:

- Understand the use of OR in real life;
- Use mathematical methods to solve/optimize certain economical problems;
- Learn how to simulate OR algorithms with applicability to real economic problems;

Based on the previous learning objectives, the proposed OR escape room was designed for a time frame of 60 minutes. It includes 4 puzzles, with different time frames. The first 10 minutes are used to introduce the rules of the game at the beginning of the game, and the remaining 10 minutes are used to debrief and collect feedback, at the end.

The escape room game is designed to be used in the OR labs, and students are divided into groups of maximum five individuals per team. Tutors are extremely important for the whole experience because they provide support and assume the role of the Game Master, who is responsible for explaining the rules and story of the game, monitoring progress, providing clues if necessary, and conducting the debriefing activity at the end of the game. In terms of restrictions, tutors must be able to manage several teams at the same time, because student groups are usually up to twenty persons. Organizing escape room activities for large groups requires scheduling multiple sessions, which can be a demanding and difficult task.

The third step of the framework is "Conceptualized", and it refers to setting a context for the escape game. A theme is usually necessary and influences the way puzzles and tasks are designed. The selected theme allows designers to specifically target and develop competencies and skills. For example, in addition to providing an enjoyable experience, an imaginative theme can stimulate creative thinking. Mystery themed escape rooms, where participants work to uncover a murderer, are ideal for problem solving and decision-making skills. These themes often emphasize attention to detail and create a more focused and serious atmosphere. On the other hand, escape rooms set in scientific or technical environments, such as a science lab or factory, can enhance team skills like strategic planning and delegation. Horror-themed escape rooms effectively foster teamwork skills under pressure. They promote adaptability and quick thinking, while also testing participants' resilience [10].

The proposed scenario for the OR escape room was formulated as follows: "The Optimization Quest: You and your team are explorers on a quest to uncover a hidden treasure buried in a remote cave on Fiji Island. Due to miscalculations the treasure's location is still unknown and you must solve a series of optimization puzzles using the graphical method and the simplex algorithm to find the right coordinates. Your time is limited, the treasure appears to be in a flood cave, and you have only 60 minutes to reach the treasure, until everything is covered with water". For the initial version of the game, there are no theme costumes or other specific accessories, being an open idea for a possible future version of the game.

The fourth step of the framework is "Design" and it involves designing the puzzles the participants will solve in order to escape the game. The game will be completed only after a team solves every puzzle in the game. To ensure that every puzzle in the educational escape room

serves its intended purpose, designers must carefully align each puzzle with a specific learning objective. Furthermore, they need to have a clear understanding of the existing knowledge and skills of the participants at the beginning of the puzzle, as well as the desired knowledge and skills they should acquire after completion [10]. As a prerequisite for the OR escape room game, students need to have mathematical skills and some basic knowledge of linear programming.

The puzzles used for "The Optimization Quest" game are presented as follows:

Puzzle 1- Graphical method (10 minutes): "First you are on your way to the cave, but you don't see the entrance. Use the graphical method and solve the following problem to reveal the geometrical shape of the entrance. Finding the exact shape will lead you straight to the cave."

$$\begin{cases} 4x_1 + 5x_2 \leq 20, & x_1 \geq 0 \\ 7x_1 + 2x_2 \leq 14, & x_2 \geq 0 \end{cases}$$
$$f(x) = 4x_1 + 9x_2$$
$$\max(f)$$

This puzzle presents students with a typical linear programming problem that they must solve using the graphical method.

Puzzle 2 - Solve the riddle (5 minutes): "You are in the cave now and you see something on the right wall that looks like a riddle, the correct answer will lead you to the next challenge in your journey."

"I am an algorithm, simple yet profound,
Solving linear problems, I am renowned.
Iterating and optimizing, step by step,
With constraints and objectives, I am adept at interacting. Named after my simplicity, I aim for the best,
Finding optimal solutions and putting skills to the test. From logistics to finance, I have wide application,
In the realm of optimization, I lead the foundation. Who am I?"

By solving the riddle, students will find the name of the algorithm they need to use to solve the problem from the next puzzle.

Puzzle 3 - As simplex as possible (20 minutes): "You are on the right track. Now you have the right algorithm to solve the following challenge and find the maximum value of the solution and you will know the number of steps you must still go through to reach the treasure."

$$\begin{cases} x_1 + x_2 - x_3 \leq 4 \\ 4x_1 - 3x_2 \leq 2 \\ -3x_1 + 2x_2 + x_3 \leq 3 \end{cases}$$
$$f(x) = x_1 - 3x_2 + 3x_3$$
$$x_1, x_2, x_3 \geq 0$$
$$\max(f)$$

In the third puzzle, students are given a linear programming problem they need to solve using the simplex algorithm. Considering that solving it involves quite a lot of effort, the amount of time given to complete the task is estimated at 20 minutes.

Puzzle 4: The hidden message (5 minutes): "You are almost done, you just have to open the box lock, and the treasure will be revealed. For this, you must find the hidden message". Students need to find the message written on the treasure. It is a simple encoding (Figure 3) and is the final step of the game. The right message in the puzzle is: "Standard form has only equal sign."

The fifth step in the framework is "Brief" which refers to the way students will be informed about the rules and narrative of the game. For this step in the OR escape game, there is a 10-minute session before starting the actual game, when the facilitator can give the introduction and rules of the game.

The sixth step in the framework is "Feedback" and is basically important for the game designers to revise, how will they ensure that participants are informed about the acquired knowledge throughout the gaming experience.

Fig. 3. Puzzle 4 in the OR educational escape room.

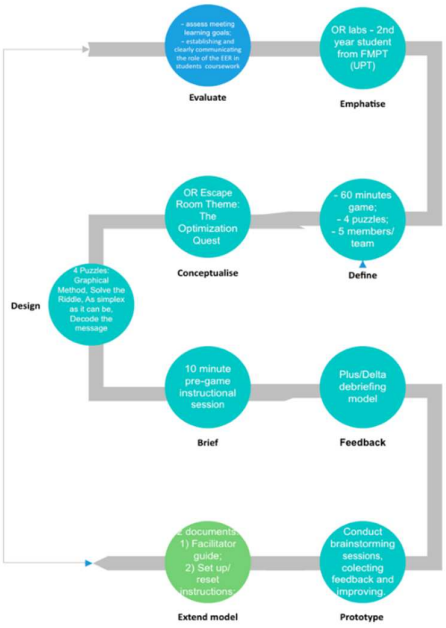

Fig. 4. Operations Research educational escape room framework.

An effective debriefing model often suggested is the Plus/Delta model, characterized by two distinct columns. The plus column (+) is designated for acknowledging positive behaviors or actions, while the delta column is reserved for identifying areas that require improvement or modification in future instances [10]. The teacher should also have a plan for giving clues where students need them and to decide if there are situations where the answers will need to be revealed if students have uncompleted puzzles.

The seventh step in the framework is "Prototype". It is very important for an educational escape room to achieve its learning objectives, so testing puzzles, making simulations, getting feedback, and improving, it is crucial for the EER success. The prototyping phase supports possible variations of player behavior, helping to develop improved and more consistent puzzles for the EER. Brainstorming with designers, specialists on the EER topic and direct feedback from potential players, can be used in the prototyping stage.

The eight steps in the framework is "Extend model". Designers should develop a highly descriptive document of the whole EER process. In addition, it is advisable to generate two additional documents. A facilitator guide is recommended, encompassing learning objectives, briefing, sand debriefing instructions, game rules, room layout, a comprehensive game walk-through that includes clues and answers for each puzzle, as well as rules and/or predetermined timings for offering hints. Second, a document comprising a visual representation of the precise placement of all objects within the room, accompanied by explicit, easy-to-follow directions on placing items for future use [10].

The ninth step is "Evaluate" and for designers involves assessing and analyzing the EER outcomes and overall performance. It aims to evaluate the success of EER in meeting its objectives and to identify areas for improvement. For the OR educational escape room, this step will be conducted using a mixed approach, using interviews and surveys. It is also very important to align the learning objectives of the EER with the tools used in the evaluation phase, because if the EER is used to assess knowledge, it requires a pre- and post-knowledge test for students to complete. It is important for students to know what the role of the OR educational escape room is in their learning process and whether it is used as a tool to assess knowledge or just to sediment knowledge. Figure 4 represents a synthesis of the steps used in adjusting the educational escape room for a subject such as Operations Research.

5. LIMITATIONS AND CONCLUSION

In this paper we present and discuss the first educational framework for escape room design in the Operations Research field. The four puzzles represent challenges students need to complete in an educational escape room framed with 60 minutes of time. The activities were designed to be relevant for 2nd year students from the Faculty of Management in Production and Transportation, in their learning process during the Operations Research course.

The paper offers an extended overview on the fact that educational escape rooms are an effective and engaging instructional method, also supported by current literature, which is increasingly consistent. The immersive and interactive nature of escape rooms promotes

active learning, problem-solving skills, critical thinking, collaboration, and knowledge retention among participants.

The Operations Research field is mainly based on mathematics and there are very few attempts to use gamification in the teaching of this subject. One of the strengths of educational escape rooms is their flexibility and adaptability to different educational contexts. Educators can design escape rooms to align with specific learning objectives, curriculum standards, and student needs. The mechanics, puzzles, and themes of the game can be customized to suit various age groups and subject areas.

The OR educational framework needs internal validation with specialists but also with students, so future research will be conducted in a subsequent study. Although educational escape rooms have shown numerous benefits, it is important to acknowledge their limitations.

Further research is needed to explore their long-term impact, scalability, and potential challenges in implementing them in diverse educational settings. Future studies could also investigate the most effective instructional strategies and methods for integrating escape rooms into the curriculum; extension of the teaching method to other subjects of study will be approached [25].

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Integrarea jocurilor de tip escape room în predarea conceptelor de cercetare operațională

Jocurile de tip Escape Room au câștigat popularitate ca experiențe de învățare captivante și imersive, dar potențialul lor de a preda concepte de cercetare operațională (CO) rămâne în mare parte neexplorat. Acest articol propune un cadru de utilizare a escape room-urilor ca instrument de predare inovator în domeniul CO la Facultatea de Management în Producție și Transporturi a Universității Politehnica din Timișoara. Cadrul este conceput pentru a spori înțelegerea de către studenți a metodologiilor CO, abilitățile de rezolvare a problemelor, munca în echipă și abilitățile de gândire critică. Adesea, studenții se confruntă cu o mulțime de provocări atunci când se confruntă cu algoritmi și metode ale CO și de aceea această lucrare își propune să ofere un mediu de învățare structurat și interactiv care promovează participarea activă și retenția cunoștințelor. Acest articol contribuie la volumul tot mai mare de literatură privind metodele de învățare experiențială și oferă educatorilor perspective practice pentru implementarea jocurilor de tip escape rooms în cadrul curriculumului de Cercetări Operaționale.

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