MAZE VIDEO GAMES FOR STEM TEACHING

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ВИДЕО ИГРИ-ЛАБИРИНТИ ЗА STEM ОБУЧЕНИЕ

Abstract

In last twenty years, STEM teaching methods are in the focus of regulation bodies, visionaries, decision-makers and practitioners in K12 and university education worldwide. Among the traditional approaches for STEM teaching based on problem solving, projects, collaboration and inquiries, nowadays gamification and game-based learning started gaining popularity as innovative, interactive and very engaging teaching methods. While gamification applies game elements and interactive simulations to teach STEM concepts, game-based learning relies on incorporation of educational content into digital games that learners play as a part of the learning process, for acquiring specific knowledge or skills. The paper presents 3D maze video games as effective tool for informal education proven in many previous case studies with K12 and university students. The video mazes are generated automatically by a software platform and are enhanced with various mini-games representing didactic tasks of different types. Despite the fact that most previous games have been in the field of cultural heritage, mazes have the potential to be used in STEM education as well. There are discussed the qualities of the mini-games included in maze halls, together with their possible application for STEM teaching. The paper concludes with some remarks about the positive appreciation of maze video games reported by both students and teachers that paves the way for their future application for a motivating and engaging game-based learning.

Keywords: *Maze Video Games; STEM; Game-based Learning; Mini-Games.*

INTRODUCTION

Since the dawn of its creation, computer games have been on a continuous rise and have attracted an increasingly large audience thanks to their interactivity and presentation of the action in the first person, in which the player himself appears in the role of the protagonist of the story. This is true both for fun games and for serious (or also called applied) video games, where the goal is different from real entertainment [1]. The majority of serious games (SG) are created especially for education and training, however, there are many examples of SG applied at the government sector, NGOs, defense, healthcare, marketing and communications, corporate sector, and industry [2]. Educational games are mainly used for game-based learning, which is plausible (not real) and characterized by relatively more freedom, uncertainty about the outcome, and non-performance [3].

Serious educational games are an effective means of retention of learners' interest by attracting their attention in much longer time than traditional approaches [4]. They are applied at many learning domains including STEM (Science, Technology, Engineering, and Mathematics). Teaching STEM through education video games appears to be ever more popular because it can capture students' attention more effectively than traditional teaching methods and, thus, leads naturally to an increased engagement and higher motivation at the learners [5],

[6]. Game-based learning platforms such as Kahoot![1] and Nearpod[2] offer a variety of educational games and resources for STEM, even interactive scientific simulations like PhET[3]. The paper presents 3D enhanced maze video games [7] as effective tool for informal education proven in many previous case studies with K12 and university students [8], [9]. These video mazes are generated automatically by a software platform and are enhanced with various mini-games representing didactic tasks of different types.

The paper is structured as follows: after this brief introduction to the topic, it outlines the main benefits and issues of teaching STEM through serious games for learning. Next, it introduces educational maze video games with an explanation of the various types on mini-games that can be embedded into the maze. Further, it explains how educational mazes can be described formally and generated automatically by means of a software platform. It follows a presentation of the potential of such maze games for STEM teaching and, finally, a short conclusion.

Teaching STEM through Educational Games

Many authors regard STEM education as a specific meta-discipline additional to the traditional teaching of science, technology, engineering, and mathematics, which represents "*an integrated effort that removes the traditional barriers between these subjects and instead focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies*" [4]. For advancing from traditional teaching to successful and effective STEM educational processes, various innovative teaching approaches must be employed [10], including redesign of relevant technologies for creation of learning environments [11]. The STEM-oriented teaching methods can be arranged into three groups according to their underlying principles and criteria [12]:

1. Group 1: *Problem-solving approaches* – involve exploring and solving problems inspired by real-world issues, including conducting practice-based methods; focus on gaining experience by practical application of the acquired knowledge and skill development, such as problem-based learning, inquiry-based learning, and practice-based learning;
2. Group 2: *Collaborative approaches* – rely on teamwork when designing and implementing collaborative projects; focused on knowledge application in a project-based or engineering context, such as project-based learning, jigsaw learning, and engineering approaches.
3. Group 3: *Innovative approaches* – try to enhance the learning experience by integrating more engaging tasks and activities; focused on knowledge acquisition while encouraging students' curiosity and competitiveness. This group includes flipped classroom, integrated approaches, gamification, and game-based learning.

Both gamification and game-based learning (GBL) are two distinct but related innovative approaches to education that can make learning more engaging, motivating, and effective. Gamification refers to the application of various game design elements in non-game contexts (including education), such as points, badges, leaderboards, and levels, with an aim to increase user (resp. learner) engagement, motivation, and participation [13]. On the other hand, GBL represents an informal form of learning, which involves the use of actual games (physical,

[1] Kahoot!, "Learning games – Make learning awesome!", Available at: https://kahoot.com/ (last view: 01-08-2024)
[2] Nearpod, "Foster a love of learning in every student", Available at: https://nearpod.com/ (last view: 01-08-2024)
[3] PhET, "Free online physics, chemistry, biology, earth science and math simulations", Available at: https://phet.colorado.edu/ (last view: 01-08-2024)

digital, or mixed) as a medium for teaching and learning [14]. Unlike gamification, which uses game elements in non-game activities, GBL integrates educational content directly into the gameplay, allowing students to learn through the experience of playing a game for achieving a total immersion of the learner while involving an indefinite time to complete [15]. Thus, gamification focuses on using game elements to enhance traditional learning activities, while GBL centers on using digital games as the primary medium for learning. Table 1 compares the key elements and main benefits of the approaches of gamification and game-based learning.

Table 1. Comparison of gamification and game-based learning

Approach / Criteria	Gamification	Game-based learning
Key Features	• Students earning points for completing tasks and receiving rewards, such as badges, certificates, or other recognitions. • Leaderboards used to display rankings based on points or achievements to foster a sense of competition and motivation. • Students' progress shown through different levels or stages based on their performance. • Tasks or assignments are framed as challenges or quests.	• Usage of educational games designed with specific learning objectives. • Immersive learning – students learn by doing, often in a simulated environment where they can experiment, make decisions, and see the consequences of their actions in real-time. • Possible incorporation of storytelling and narrative – for more engaging and memorable learning experience. • Development of problem-solving skills and critical thinking.
Benefits	• Increased motivation (by the use of rewards and recognition). • Enhanced engagement – gamified elements can make learning more fun and engaging. • Immediate feedback – students receive instant feedback on their progress.	• Active learning with enhanced retention and understanding • Higher educational outcomes through gameplay • Collaboration and social skills (for multiplayer educational games) • Contextual learning (relevance of the courseware to real-world)

In recent years, many serious video games have been specially designed for STEM education to engage students in learning complex concepts through interactive and immersive experiences. Such digital games are tailored to teach specific STEM subjects and skills and usually integrate tasks for fostering problem-solving, critical thinking, and creativity. For example, Minecraft for Education [16] is applied to teaching mathematics, computer science, engineering, and environmental sciences. Playing this version of Minecraft, students can build and explore virtual worlds and even can code exercises to automate game tasks, while learning about specific STEM concepts. Good examples of educational games for teaching physics and engineering are Kerbal Space [17], where players can build and manage their custom space program including the construction of shuttles, and Portal 2 [18], where players must solve puzzles by manipulating objects. Playing both these games requires an understanding of basic physics concepts and good problem-solving abilities. Other platforms like Roblox Education [19] provide resources and tools for creating small games and, thus, help students learn to code and design games.

EDUCATIONAL MAZE VIDEO GAMES

The educational video maze games provide an effective tool for GBL of various disciplines including STEM. Traditionally, labyrinths and maze-like structures are popular in promoting critical thinking, problem-solving, and engagement among players [20]. They appear an excellent tool for teaching because the maze topology is very suitable for representation of the structure of a learning course, a module, or lesson, without any restriction regarding complexity and level of embedding of units. The APOGEE platform supports enhanced 3D educational mazes [7] introducing several new concepts, which enrich the basic form of a maze game and provide facilities for a more sophisticated GBL, as follows:

1. Each hall (room) of the maze may contain learning boards presenting didactic multimedia content. Of the content is longer than the size of the learning board, it is automatically paginated whereupon the player has access to the next/previous page and to the final/starting page, by pressing one of the four buttons, which appear below the learning boards with paginated content;
2. Each door to another maze hall (room) may contain a door-unlock question about the didactic concepts and/or processes presented on the learning boards in the current hall where is the player at the moment;
3. Enhanced 3D educational mazes use a maze as a container of mini-games of various types representing didactic tasks. The mini-games are placed at different places in the maze halls (rooms) and might be mandatory or optional for a player with specific profile [9]. Even more – players with different profile may see different mini-games while being at the same hall of the maze. Thus, one maze game may be tailored for individual players upon the specific player's profile including characteristics such as learning/playing style, preliminary skills, needs, goals, and others [21].

All the elements of the mini-games are customizable through XML-based game settings. Figure 1 presents a snippet of XML code for a sample memory mini-game and the generated mini-game.

```
<GameMemory Points="10" Mode="2">
<!--Mode:1-word to word, 2-word to picture, 3-picture to picture-
->
<Rows>4</Rows>
<Cols>5</Cols>
<EndText>Congratulations! You have found all pairs of tiles.
</EndText>
<Tiles>
 <Tile TileId="1">
      <Word>Филип Тотьо</Word>
      <Picture>hall3-game1-1.jpg</Picture>
 </Tile>
 <Tile TileId="2">
      <Word>Сирма войвода</Word>
      <Picture>hall3-game1-2.jpg</Picture>
 </Tile>
 …
</Tiles>
<Hints>Find the equal tiles.</Hints>
</GameMemory>
```

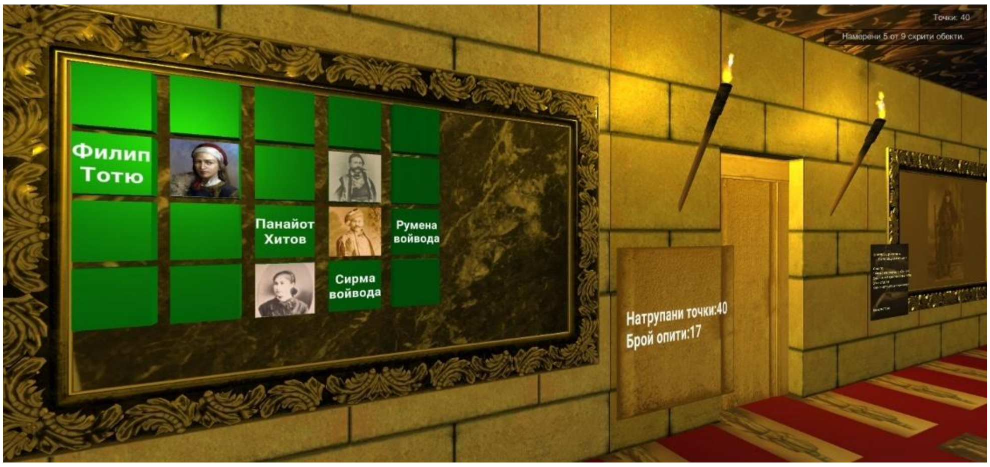

Fig. 1. XML code for a sample memory mini-game (left) and the generated mini-game (right)

AUTOMATIC GENERATION OF MAZE VIDEO GAMES

One of the great advantages of maze video games is their ability to describe the maze structure (i.e., hall interconnection topology) in a formal way. Either irregular or regular (i.e., pattern-based), the maze topology can be formally described by a mathematical, program, or XML-based language. While a program can easily generate a maze with a pattern-based structure, mazes with irregular (custom) structures can be generated through their formal descriptions. Custom mazes are very attractive for educational needs as their structure can naturally repeat (or resemble) the curriculum, module, or lesson. Learning content design includes setting learning goals and selection and structuring of didactic content (Fig. 2). The APOGEE platform supports XML descriptions of enhanced 3D educational mazes that can be created manually or automatically [8] (step 4 in Fig. 2). It presents the maze topology, audio-visual environment of each of the maze halls (including music and audio effects in the hall, textures for the hall walls, floor, and ceiling), didactic content on the learning boards, questions for unlocking doors, descriptions of 2D and 3D mini-games and models located in maze halls, and some maze game settings, e.g. for some non-player characters (NPC) representing tutors of the real player. Next, the maze can be generated from the validated XML description directly in Unity 3D Editor via a specially created plugin [8] (steps 4 and 5 in Fig. 2). After the maze has been generated in Unity, the educator can arrange locations of game assets and edit their representation or content and, finally, build and deploy the video game as a desktop, online, or mobile game (steps 7, 8 and 9 in Fig. 2). In the last six years, many educational maze video games were designed and created using the APOGEE platform. While some of them are dedicated to Bulgarian history [9], others were focused on issues of climate change built regarding cultural heritage, such as climate heritage resilience, vulnerability, impact, and adaptation [22]. All the created educational maze video games were successfully validated through practical experiments conducted with students from K12 schools and universities in Europe and Turkey. The conducted experiments proved that maze games enhanced by embedded mini-games of various types possess high learnability and provide engaging and motivating player experience.

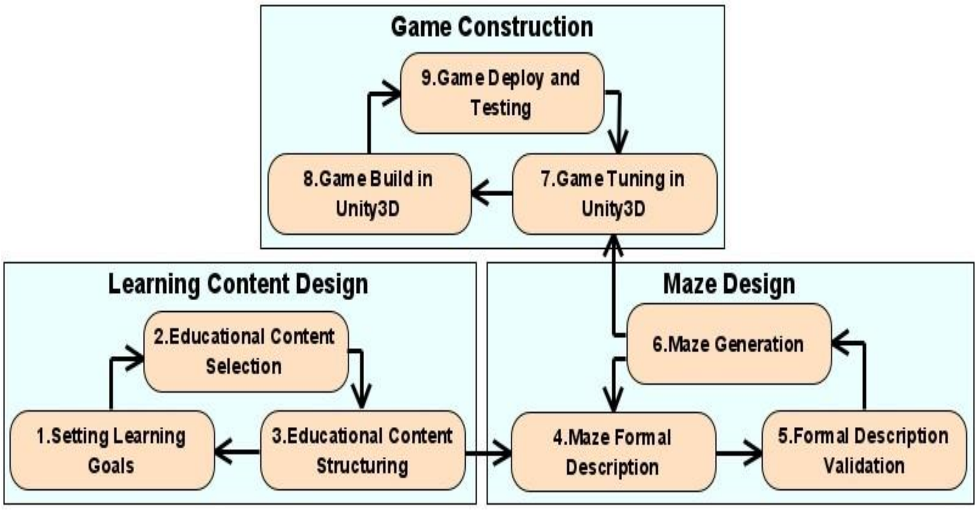

Fig. 2. The process of creation of educational video maze games [9]

THE POTENTIAL OF MAZE VIDEO GAMES FOR TEACHING STEM

Until the present, the APOGEE platform supports five types of mini-games available for embedding in maze halls [8]:

1. *Question-based games:* involve answering a quiz or solving individual problems. Customization options include choosing the format of questions (open-ended or multiple choice), the level of difficulty and complexity, the number of answers, and the provision of hints.
2. *Search-based games:* require players to find or match objects, such as finding semi-transparent or hidden game assets or solving "word soup" puzzles. The variety in such games can include differences in the number, size, and type of objects, words, or items, as well as the matching criteria and object positions in maze halls.
3. *Matching games:* require players to find or match objects, such as pairing memory cards or rolling balls with given descriptions to specific objects or positions on a map.
4. *Arrangement games:* focus on assembling a 2D image or sorting/arranging objects according specific criteria, e.g. creation time, size, importance, etc. Teachers can change the content, shape, and size of pieces of an image, adjust the number and type of objects, and set different classification criteria for sorting.
5. *Action games:* provide activities like shooting (e.g., balloons with attached 3D educational items) and collecting fallen objects. Customizable aspects include the number, size, and types of objects involved. (e.g., balloons with attached 3D educational items).

Table 2 presents the types of mini-games available at the APOGEE maze games platform, the mini-games supported for each one of the types, and some ideas about their possible application in STEM education. It contains yet another type of mini-games – *simulation games* – planned for implementation and integration in the educational maze and especially appropriate in learning physics and climate change actions such as resilience and adaptation. Two mini-games have been proposed here – flooding and electromagnetic fields – that can be applied for teaching various lessons in physics. Besides these mini-games, educational mazes might provide various 3D models and NPC (assisting the player in acquisition of new knowledge, solving puzzles, etc.) instances appropriate for teaching STEM concepts and processes.

Table 2. Types of mini-games and their possible application in STEM education

Approach / Type	Mini-games	Application in STEM education
Question-based games	• Door unlock • Quiz	• Making decisions and see the consequences of their actions in real-time. • Checking their problem-solving skills and critical thinking.
Search-based games	• Word soup • Hidden objects • Finding assets	• Students learn actively with deeper comprehension of the concepts • Facilitates contextual learning with a relevance of STEM theories to real problems

Matching games	• Rolling balls to:
	  ○ Objects
	  ○ Locations on a map
	• Memory game
	• Classify me!
		• Finding inter-relationships among STEM concepts and their instances
		• Memorizing easily facts and data
		• Gameplay based on STEM classification tasks

Arrangement games	• Image puzzle • Arrange me!	• Practicing induction and deduction principles • Finding patterns and time sequences
Action games	• Balloon shooting • Fallen load collecting	• Improving hand-eye coordination • Learning facts about game assets
Simulation games	• Flooding a hall • Electromagnetic fields	• Real-time simulations of inundations • Creating problem-solving skills

CONCLUSIONS

Game-based learning continues being one of the attractive and innovative methods for teaching STEM, together with flipped classroom, integrated approaches, and gamification [23]. Recently, in the scope of the SHAPES project[4] (reSearcH on formAl models for the oPtimization and pErsonalization of modern technological methods of STEM education), a qualitative pilot study was conducted aiming at investigating STEM teaching methods and the conditions for their successful implementation at Bulgarian schools and integration into course curriculums [24]. The preliminary results reveal that educational games are still underestimated in STEM disciplines despite their significant potential to motivate learners and engage them in a deeper and immersive learning process. Hence, further efforts are needed for a broader integration of GBL in course curriculums and popularization of educational video games among teachers and educators as a powerful tool for a self-learning.

3D maze video games enhanced with various types of mini-games represents an appropriate instrument for modern GBL and are proven to bring an enhanced learning experience by integrating more engaging didactic tasks and activities. Their ability for a straightforward formal description and an easy automatic generation promises to facilitate teachers in creation of custom educational games appropriate for teaching STEM. At the same time, more types of mini-games are required for a successful and effective STEM learning encouraging students' curiosity and competitiveness.

[4] "SHAPES project", Available at: http://shapesproject.eu/ (last view: 01-08-2024)

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