ΠΡΑΚΤΙΚΑ ΕΡΓΑΣΙΩΝ

του 3ου Πανελληνίου Συνεδρίου Scientix για την Εκπαίδευση STEM

Αθήνα, Πολυτεχνειούπολη Ζωγράφου
23, 24 και 25 Σεπτεμβρίου 2022

ΤΟΜΟΣ Β

ISBN 978-618-84221-4-8

Επιμέλεια: Κατερίνα Γλέζου, Ιωάννης Λεύκος, Κώστας Παπαδήμας

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This event is supported by the European Union's H2020 research and innovation programme - project Scientix 4 (Grant Agreement N. 101000063), coordinated by European Schoolnet (EUN). The content of this material is the sole responsibility of the organiser and it does not represent the opinion of the European Commission (EC), and the EC is not responsible for any use that might be made of information contained

AR Educational Escape Room in STEM – "Newton's Kidnap"

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ABSTRACT

STEM education involves a huge range of strategies that help students apply concepts and skills from different disciplines to solve meaningful problems. Instructors across science, technology, engineering, and mathematics (STEM) disciplines have begun to implement escape room activities as effective and engaging learning tools in their classrooms. Educational Escape Rooms (EER) epitomize the concept of problem-solving and out-of-the-box thinking. The current study examines the effects of a Mixed (Physical and Digital) Educational Escape Room ("Newton's Kidnap") on STEM principals, deeper subject comprehension, motivation and engagement using Engino robotics for students 8-15 years old. We created a STEM-based EER for kids who participated in a robotic summer camp in Cyprus. At the end of the lessons the students, in small groups using an Augmented Reality app "Newton's Kidnap", tried to escape from a hotel room that was transformed into Newton's Lab. We evaluated the whole experience through a validated questionnaire to 40 of the 56 students that played the game. Results indicated that mixed escape rooms using digital storytelling and hands-on activities (like building robotic models) can enhance the cognitive benefits and learning outcomes, motivate and help students of primary and secondary school cooperate, via an enjoyable experience.

KEYWORDS: *educational escape room, robotics, Engino, STEM.*

INTRODUCTION

Political and socioeconomic stakeholders, as well as school research, points to the lack of coherence between societal development and experienced priorities in schools (Organization for Economic Co-operation and Development [OECD], [Organisation for Economic Co-operation and Development (OECD). (2010)] [Organisation for Economic Co-operation and Development (OECD). (2012)]; [Sawyer, R. K. (2012)). In policy documents, we now see that the aim of schooling is focused on the future requirements for coming generations, as operationalized through the identification of key competencies for the future [European Commission. (2018a)] and 21st-century skills such as those needed for lifelong learning, innovation, career, life, and digital literacy [Partnership for 21st-century skills. (2014)]. This new direction calls for further development and changes in curricula. Educators continually turn to innovative methods to engage their students and, as such, several have begun to develop educational escape rooms for this purpose [Lene Hayden Taraldsen (2020)]. As regards the levels of education for which the proposals (escape rooms) are designed, most of them targeted tertiary education, so there is a great potential for development, especially in the field of secondary education (and also primary education). [Chantal Lathwesen (2021)].

The current study tried to bridge the gap in knowledge relating to mixed educational escape rooms on STEM and its effects in elementary and lower secondary schools. As far as we know, there is no other study now that could offer insights to researchers and educators on the effects of the mixed (physical and digital) escape room and its application as a learning tool aimed to STEM principles in a summer school.

EDUCATIONAL ESCAPE ROOM, ROBOTICS AND STEM

According to the research of Columbia University, any training should include education on challenges that have environmental, social-economic and political impacts so that the students can face such issues. A nation with deep knowledge not only reads, but also calculates, inquires, and innovates. Robotics confronts students in the four areas of science, technology, engineering and mathematics (S.T.E.M) through the design, creation, and programming in tangible objects for creating personal items facing real social needs.

Escape rooms are used for various educational purposes. Case studies show that most escape rooms were designed for formal education to foster domain-specific skills and knowledge, mostly in medical (Jenkin (2019)) and science disciplines (Vörös 2017); (Dietrich, N. (2018)); (Ho (2018)); (Arnab, S.(2015).), (Healy, K. (2019)). Others were implemented to recruit students, to get to know institutional services (Gilbert, (2019)), or in informal education to create interest in specific science subjects, such as robotics (Giang (2018)). Educational escape rooms are useful to teach soft and hard skills and they follow three learning theories: behaviorism, cognitivism, and constructivism. Unfortunately, very few articles related to escape room in elementary and secondary education are published.

The three proposals for primary education were published by Vidergor (2021) about the effects of digital escape room on gameful experience, collaboration, and motivation of elementary school students, Huang, (2020) that investigated 4th grade elementary students' motivation and problem-solving skills and finally Juho Kahila (2020), that explored CT Learning Activities in the Primary School. Adam Clare, a Professor of Game Design and Director of Interactive Education at George Brown College, and Web producer of experience escape rooms (LA, SCRAP Room Escape, Escape Games, Inside Out Claustrophobia), argues that the first step in designing an escape room is the choice of a topic, which creates the proper framework, helps "the metaphor of narration and justifies the challenges that players should experience" (Clare, A. 2015). In his view, the topic should not be limited to physical space, where the game takes place, but it can, and probably should be spread in the field before the game or even in the entire available space that is allowed at a time (Nicholson, S (2015)). According to Duplessie, creating an escape room as a replayable experience from the beginning, can change their player experience so that is more about having the adventure and less about doing the static puzzle. They found three things that players consistently enjoyed: being part of a spectacle, feeling heroic, and engaging with something challenging (Duplessie, M. (2013)). By creating these three things, it immerses players in a narrative where they are part of an adventure.

The dynamic of educational robotics leads young students to construct a mechanical model (for example a car model) and direct it with the help of a simple and useful programming environment. Its positive effects are recognized in both the cognitive, emotional (self-esteem, self-confidence), and social domain (socialization, demystification). Moreover, through this, educators can focus on the development of more crucial skills of the 21st century such as teamwork, problem-solving, (analysis, design, implementation, testing, experimentation, and assessment), innovation, management, programming, communication skills, valuable intellectual skills (analytical and complex thinking, creativity, critical thinking, etc.). Educational robotics creates an appropriate learning environment where learners acquire an integrated package of skills useful for their future by using tangible materials (Bradley 2012). Our goal was to create an EER combined with educational robotics, named "Newton's Kidnap", that can be easily settled and reused many times without being destroyed by enthusiastic primary and secondary students. For the development of the EER, we used Engino STEM & Robotics (https://enginoeducation.com/), which is specially designed for late Primary and Secondary school students of ages 8-15, and we implemented it in a summer school in Cyprus. It combines the core subjects of STEM together with Robotics. The activities began with the basic principles of STEM-related subjects together with robotics using easy-to-build models. Then, they moved on to more complex concepts including sensors, conditional statements, variables, functions, and operators

AIMS

This paper aims to present the design of an Augmented Reality (AR), STEM-oriented Educational Escape room for primary and secondary students that took part in Engino's Summer Camp in Cyprus. According to the STEM escape room questionnaire, we would like to investigate 5 different fields of adapting EER in STEM camps:

- Interest;
- participation, motivation;
- cooperation;

- easy to use activity; and
- content knowledge.

Thus, the research questions in this study are the following:

16. How interested are kids to learn new things through STEM-oriented EER?
17. Can we achieve mass participation and cooperation using EER among kids in a STEM workshop? (that are not friends or classmates?)
18. Is an EER an easy going, entertaining activity for kids?
19. Have the kids learned new things using STEM EERs?

The results can highlight the benefits of STEM Educational Escape Room and help teachers to implement these learning environments more effectively to help foster students' science knowledge and soft skills.

DESIGN OF THE EER "NEWTON'S KIDNAP"

For the design of the digital escape room "Newton's Kidnap", we took into consideration the following aspects:

(vii) detect and analyze the characteristics, needs and interests of the players, who were kids 8-15 years old, mostly boys who had spent together a few days in a summer camp,

(viii) formulate our STEM learning objectives in the cognitive and playful narrative that can transfer our players to a time travel journey full of surprises,

(ix) select the kidnap as an appropriate theme to inspire and keep students engaged to the story

(x) design the characters and embody facts of the real life of great scientists and their enemies (like Newton, Leibniz, Copernicus, Euclid, Galileo),

(xi) design missions, activities, hints, and puzzles aligned with robotic learning objectives of Engino using Newton's inventions,

(xii) select and create components, clues, and props that can be reused several times from each team,

(xiii) develop and program appropriate apps (in two languages, Greek and English) that can describe every mission shortly and clearly for all kids,

(xiv) test the escape room from instructors and making necessary changes,

(xv) reschedule the timeline of the flow so as the most difficult missions to get in the middle of the game,

(xvi) prepare the needed props with laser cutting, printers, and buying useful elements like boxes, padlocks, locked boxes, UVpens, etc.,

(xvii) debrief and share questionnaire after gameplay to evaluate the whole experience.

The designing process had a lot of steps and started with brainstorming among the educational team so as the appropriate **narrative** to be selected. We needed an adventure of a relevant scientist with the lessons that the kids had attended to the summer camp. We had chosen Isaac Newton because the kids at the camp had get in touch with Newton's Inventions and his 3 Laws of Motion. Deep research on Newton's personal life, studies, habits, and scientific resources as well as the social and historical background of that period was important for our story.

The next step was the choice of the **software** that could made our story interactive and playful. We selected Go Meta's earlier platform, Metaverse Studio, which is a web application that allows users to create interactive Augmented Reality experiences with QR codes, digital coins, multiple choice questions, video and GIFs.

Storyboard and riddle connection had to be simple and straightforward for the players. In his 2015 survey of escape facilities, Nicholson [Nicholson, S (2015)] makes a brief summary of how narratives, if used, can be told through escape rooms. The first example is telling a story through the use of audio or environmental storytelling, using props, to suggest a story to the player. Another method is to tie the puzzles directly into the narrative itself, thus helping it develop and move forward to the next step of the story. We combined these techniques and we started with storytelling in order to dive into the imaginary adventure and then puzzles and hidden clues moved the team to the next step of the flow until the final mission, the escape from the room.

There is a variety of **puzzles** like pattern identification, riddles, ciphers, light, physical agility or strategic thinking and many more (Nicholson, S (2015)) that can be used in an escape room. Our intention was to create an interesting, addictive experience that stimulates kids' mass participation, cooperation, motivation, problem solving, and also to help students to consolidate the knowledge taken of the summer camp of Engino. Missions were made with different difficulty levels because inclusion was a vital principle for us. The designer started with simpler puzzles and then move into more difficult puzzles as the players grow in confidence and familiarity. At the end they combined hidden clues from all the previous missions because to ensure that they didn't skip or cheat.

On the table you can see the kind of puzzles we choose for our Escape room compared with the most popular according to Nicholson (Nicholson, S (2015)).

Table 1: *Types of Puzzles in our escape rooms comparing with the most popular*

Puzzle types	***Preference***	***Used by Newton's Kidnap ER***
Searching for physical objects hidden in the room	78%	√
Team Communication	58%	√
Light	54%	√
Counting	53%	√
Noticing something "obvious" in the room	49%	√
Symbol substitution with a Key (such as looking symbols up in a book)	47%	√
Using something in an unusual way (Out-of-the-box thinking)	47%	√
Searching for objects in images	43%	√
Assembly of a Physical object (such as a jigsaw puzzle)	40%	√
Algebra and other Mathematics	39%	√
Pattern identification (such as visualizing a shape in a set of dots)	38%	-
Riddles	37%	√
Ciphers without a Key (such as letter substitution)	35%	√
Hearing	26%	-
Mirrors	26%	√
Abstract logic (such as Sudoku)	22%	-
Research using information sources	20%	-
Strategic thinking (such as Chess)	20%	√- Computational Thinking
Hand-eye Coordination (such as shooting a target)	17%	√
Rope or chains (such as undoing complex knots)	16%	√
Traditional Word Puzzles (such as crosswords or word search)	14%	-
Mazes	14%	-
Physical Agility (such as a laser maze)	13%	-
Touch	12%	-
Knowledge of facts not provided in the room	11%	√
Shape manipulation (such as a matchstick puzzle)	11%	√ -Robotic construction
Liquids	9%	-
Social engagement with actors	7%	-
Physical engagement with actors	4%	-
Smell	3%	-
Taste	1%	-

The flow was sequential and the app had eight different missions to be solved. The gamemaster was the teacher of the four days robotic summer school that the students attended. For safety reasons, the instructor was present with the kids. This was convenient for the smaller students because they could ask for help, which could cost them loss of time.

The missions were described in the AR app and a tablet was given to the gamemaster. They had to find out in an hour the name of the kidnapper, his hideout, and the final mission was to unlock the door and get out. More analytically the missions were the following:

Table 2 *. Missions of EER "Newton's Kidnap"*

Missions	***Clues***	***Props***	***Solution***
5. Newton's Year of birth	Mirrored Birth Certificate	Mirror	1643
6. Newton's Law of …	Letter to Leibniz, his enemy	Book, red letters encrypted by Newton's technique (1M1A2S= MASS)	Mass
7. Newton's favorite inventor	EUCLID, COPERNICUS, GALILEO	3 posters, one hidden key	EUCLID
8. Newton's gravity law	Coded message on an apple	Chest, apple, UVpen, key, decoder	GRAVITY
9. Newton's university	Hideout of kidnappers	Tangram of a map	CAMBRIDGE
10. Newton's inventions	Key from mission 4	Locked box	Construction of robotic model
11. Newton's kidnapper	Suspect	Riddle of computational thinking, UVpen	HOOK
12. Breakout mission	Combination of previous clues	Number locker, entrance mat	512

The escape room was developed to be implemented at two hotel rooms but can be adapted to any installation. It's worth mentioning that "Newton's Kidnap" is a mobile EER which is a serious restriction for the designing because all the hidden objects, puzzles and riddles that emulate a traditional escape room should be settled by the instructors and moved away. On the other hand, it gives it flexibility to be set in a classroom, a library, etc.

At the end, we made sure that the 2 hotel rooms that we needed can be available for us with stable internet connection for our pre-test and the final settings of the scenario. We used all the furniture and we prepared the room to look old and violated by the kidnappers.

METHODOLOGY

Students attended a well-organized innovative, interactive robotic workshop of Engino STEM camp in Cyprus for 3 days. Students used a tablet and they scanned a QR code to load the "Newton's Kidnap" app, which is a metaverse application in augmented reality that describes the missions that each team had to accomplish in an hour. They took part into small groups to an educational Escape Room that took place in two hotel rooms solving different kind of quizzes and riddles focusing on robotics and engineering.

The participants were organized into nine groups of six players according to the groups of the lessons that they attended, the age, and their spoken language (Greek or English). Each team with the help of an organizer and a tablet scanned a QR code with the "Newton's Kidnap" app, get into the room and a timer started to count backwards. The gamemaster explained the rules to the team as well as the restrictions for safety reasons. The door closed and nobody could leave the room or use his phone to ask for help. The narrative was described at the beginning of the app and was clear and simple:

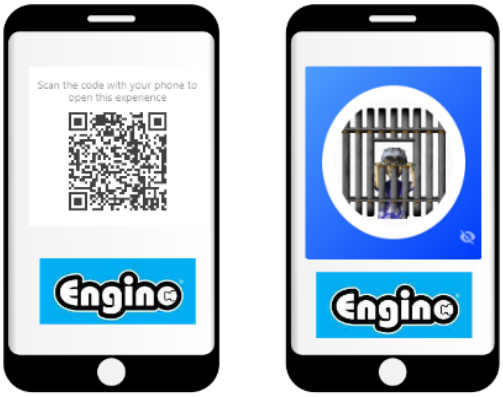

Image 1: *QR CODE of "NEWTON'S KIDNAP APP"*

"Newton is a genius scientist. But he was captured by a paranoid inventor who uses his to perfect his own intelligence. Enter the time capsule and in 1 hour find the kidnapper and his hideout to return him to his time because chain reactions in the time sequence have changed the course of the story. Hurry up before the kidnapper returns and you are in danger too."

The first four missions were established to the first room and the rest four to the second room. Whenever they had difficulties, the instructor could help them, but the punishment was loss of time. The model construction "Gravity Fan", Engino Newton's Laws was split in parts so as to finish in time. Each mission was different so as to engage and help the contribution of as many participants as possible regardless their abilities and skills. At the final escape, they could take a selfie of their accomplishment to remember their experience.

Image 2: *Newton's Laws construction models (Engino)*

RESULTS – SURVEY

At the end of the EER, 40 of 54 kids 8-15 years old took part to anonymous questionnaire about their experience. Half of the participants (52.5%) were 11-12 years old. The gender distribution was quite asymmetrical, with the girls being considerably (12.5%) less than boys. Unfortunately, this is a fairly representative picture of the Cyprus education landscape considering STEM camps. Almost half of them had a previous ER experience. An important ascertainment is that 85% of all the participants would like to participate in a similar activity in the future and only 7,5% were neutral and 7,5% negative, which highlights the importance of EER as a useful, engaging, learning tool. Even though 87,5% of the participants found the activities interesting, only 62,5% of them learned something new in escape room and 22.5% were neutral. We designed an escape room that was focused to revision and knowledge comprehension of the Engino STEM workshop regarding the content knowledge.

We divided the whole Escape room experience into four separate parts: puzzles, treasure hunt, quizzes, and model building to discover the most educational and joyful type of missions. Even though 87.5% liked treasure hunt very much, 82,5% liked puzzles, 79,5% quizzes and 67,5% model building they claimed that if they had to choose the most educational of all then they would prefer quizzes (45%) (both boys and girls), then model building (20%) and treasure hunt (20%), and at last puzzles

(15%). This needs further investigation, because the missions related with model building and puzzles were more difficult and time-consuming which seemed to be an obstacle for the time challenging experience of the escape room.

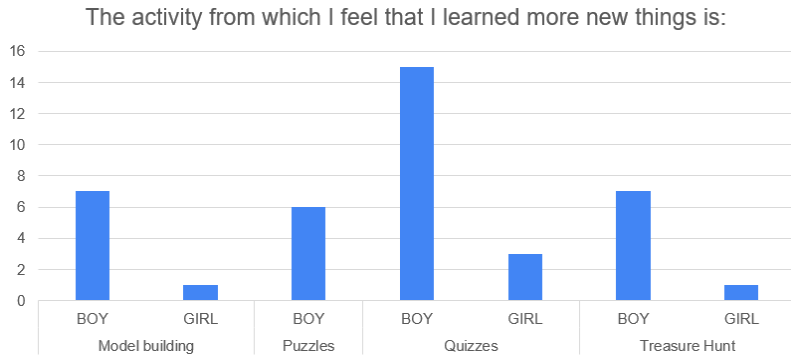

Image 3: *Graph of "The activity that I learned more new things"*

Self-esteem and team building was certainly achieved because 87,5% appreciated the contribution of the rest members as valuable and 74% of participants considered their contribution to this experience very important. This was very significant achievement for our project because we aimed to mass participation and inclusion of the participants, regardless of their personal friendships.

Collaboration and communication skills are essential skills in order to understand and solve the content-based puzzles. Another useful result is the clear belief (90%) of the players that team's cooperation plays an important role to the solution of the escape room. 83% of students wanted to collaborate with others and 80% of them managed it. It is interesting that the only one student who claimed that cooperation wasn't good had also answered that he didn't like to work with other team members, even though he found the activities very interesting.

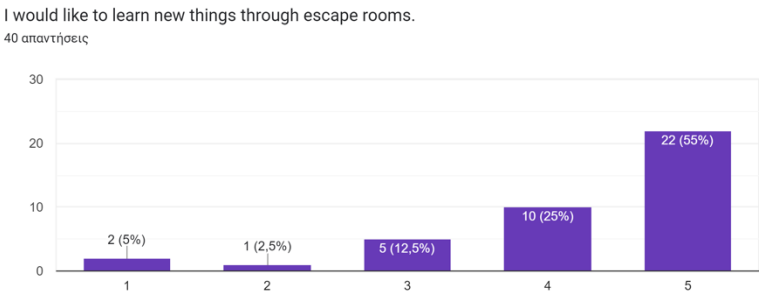

Image 4: *Graph of "I would like to learn new things through escape rooms"*

As a closure we would like to mention that, 100% of our sample would like to learn new things through escape rooms and only 7,5% claimed that they didn't learned. That result indicates that the participants had an innovative, educational experience even though we have to clarify exactly the fields of the knowledge acquired, in further research. Students found the escape room activity to be an interesting, engaging, cooperative, learning activity for application of skill, teamwork, participation, and problem solving in a high-pressure situation. This suggests that the aim of the escape room was achieved.

CONCLUSIONS

According to our research, EERs seem to be an engaging way to "gamify" STEM learning and promote motivation, collaboration and interest for primary and early secondary students. This challenging trip expands students' skills, supports the educational objectives, and stimulates curiosity on learning at the field of S.T.E.M. Kids were very interested to learn new things through STEM-oriented EER and participated massively even though the rest team members are not their close friends. Team's cooperation played an important role to the solution of the escape room for almost all the students who tried to collaborate with others for the final escape, which was the common purpose.

However, a much more systematic approach is needed to provide more evidence. First, we propose the creation of a database where available educational escape rooms can be collected and can be easily browsed and divided by subject and age. We should also take into consideration that

inclusion is necessary especially for kids with special needs. STEM activities is a great field that encourages a multidiscipline approach of everyday problems that can be a great scenario for any escape room. Second, there is a general need for larger scale studies with observation or feedback questionnaires especially in primary education. At last, since EER promotes 21st century skills (4Cs), it would be very interesting to compare the impact of a physical Escape Room with a mixed EER of virtual or augmented reality technologies as far as the motivation, collaboration, creativity, communication, and creativity.

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