Enter the Serious E-scape Room: A Cost-Effective Serious Game Model for Deep and Meaningful E-learning

Stylianos Mystakidis
Faculty of Information Technology
University of Jyväskylä & Patras
Jyväskylä, Finland & Patras, Greece
smyst@upatras.gr

Enrique Cachafeiro
OESO
Duke Health
Durham, USA
enrique.cachafeiro@duke.edu

Ioannis Hatzilygeroudis
Department of Computer Engineering & Informatics
University of Patras
Patras, Greece
ihatz@ceid.upatras.gr

***Abstract*— Escape rooms are a phenomenon that has taken the world by storm in the last decade. Simultaneously Virtual Reality is a promising technology for innovation in education, training and e-learning. Combining these two concepts, this paper outlines a new model for designing serious games in virtual reality environments for high quality, deep and meaningful learning, the Serious E-scape Room. It describes the theoretical grounding, general guidelines and principles of the model. It also presents the case study "Room of Keys", a serious virtual escape room for biology concepts. To test the assumptions of the model, researchers conducted a mixed research study with 148 students in a US high school. Pre-post test results recorded a 13.8% performance increase and high overall satisfaction. The game has been received enthusiastically by students, it increased their motivation and helped them build a deeper understanding of the learned concepts.**

Keywords—escape room, virtual reality, serious games, deep and meaningful learning, biology

I. INTRODUCTION

Virtual reality (VR) is a technological field with origins in analog, mechanical systems such as the Sensorama [1]. VR re-emerged in recent years offering psychological and sensory immersion [2] through digital, computer-generated virtual environments. Desktop VR environments have been utilized effectively for a long time in education [3]. Educators have been able to design and develop innovative, immersive resources, environments, experiences, such as simulations and games for teaching and learning [4]. VR experiences are currently being used mainly for entertainment but also for educational purposes [5]. As new VR software platforms and hardware such as head-mounted displays and peripherals emerge in quick pace, it is essential to provide affordable tools and paradigms for educators to adopt VR and use it effectively for high quality, deep and meaningful learning experiences.

In this paper, we present a new model for designing mini serious games in VR environments, virtual escape rooms. We present the design and development of the awarding-winning educational serious escape room "The room of keys", for learning biology concepts. We also provide preliminary evaluation results from first user experiences breaking out of the virtual escape room.

II. BACKGROUND

A. Deep and Meaningful E-learning

Deep learning is the result of a deep approach to learning. This approach is characterized by an intrinsic interest in the subject matter and a drive to understand the underpinning principles behind studied phenomena and processes [6]. Deep learning thus is durable and interconnected with existing knowledge.

Meaningful learning occurs when learning is active, constructive, intentional, authentic, and cooperative [7]. More specific, meaningful learning experiences include tasks linked with *authentic*, realistic context so that new competences can be transferred and applied in real settings. In these experiences, learners participate *actively* to make a personal cognitive contribution by interacting with content materials and learning environments. Their actions should be *intentional*, self-directed towards their own individual goals and serve the *construction* of personal interpretation and meaning through reflection on new knowledge and observed phenomena. This sustained critical discourse takes place in a knowledge community with *collaborative* tasks that involve both teachers and co-learners [8].

These two concepts have correspondences in their structure and thus have been unified in the term deep and meaningful learning [9]. The achievement of deep and meaningful learning is challenging in e-learning where learning quality and drop-out rates are constant concerns [10]. Addressing e-learning participants' emotions and intrinsic motivation improves deep learning and performance [11].

B. Escape rooms in Education

Appropriately designed gameful and playful motivation enhancement methods such as gamification and serious games can empower learners to develop and adopt autonomous, intrinsic goals, increase their engagement and facilitate deep and meaningful e-learning [12], [13]. Serious games are experiences that offer a set of meaningful choices with a primary educational purpose [14].

Escape rooms are a new type of leisure spatial activity originating from Japan that are spreading rapidly world-wide in the last decade [15]. Escape rooms are defined as live-action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order

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to accomplish a specific goal (usually escaping from the room) in a limited time [16]. Currently there are estimations of 10,000 operating escape rooms globally [17]. Escape rooms are usually themed and sometimes driven by a narrative where players engage in role play. Popular themes are modern era, historic, horror, fantasy, science, future (sci-fi), military [18]. Escape rooms have been used successfully for educational purposes in higher education [19], [20].

III. The Serious E-scape Room Model

The concept of breakout rooms can be transferred also in virtual, computer-generated environments. Leisure virtual and augmented reality escape rooms produced in physical locations are an emerging trend in the escape room industry [21]. From a technical point of view, virtual escape rooms are a good fit in the current generation of VR platforms and mostly tethered peripherals, as they require limited physical space and movement. Interactions in VR escape rooms should be designed carefully to avoid technical pitfalls and gain the trust of players [22].

Virtual reality is the ultimate empathy machine for education, as it allows users to immerse themselves into transformative experiences of the self [23]. The potential of VR for simulated procedural training is established [24] and will grow proportionally with the fidelity of peripherals such as gloves that monitor accurately finger movement. However, educational solutions from both categories require special technical skills, are complex and costly to develop. There is a need to democratize immersive education and make VR learning apps an attainable aim for all educators.

Educational virtual escape rooms as a special genre of serious games seeking to balance entertainment with education, fun with learning. Educational virtual escape rooms have been developed successfully to address psychological phobias [25] and team-building in corporate groups [26]. Combining organically content within a narrative, a story, rearranges learning into an appealing experience that facilitates agency and mastery [27].

The proposed model of Serious E-scape Room unites virtual escape rooms with deep and meaningful learning theories. Serious E-scape Rooms are educational game-based and problem-solving experiences in virtual online environments with a special focus on deep and meaningful learning. Serious e-scape rooms provide learners with challenging activities and puzzles they can undertake autonomously from a distance in an authentic context, narrative or theme [28]. Participants are invited to act, explore, identify, think, experiment, solve problems, communicate, discuss, coordinate, distribute roles, collaborate and reflect, so as to build mental connections between new and existing knowledge. Additionally, these experiences when designed effectively can attract the attention, and create a pleasurable atmosphere that excite and enables intrinsic motivation. Hence, serious e-scape rooms can address the cognitive, emotional and social domains of learning in a cost-effective manner. Therefore serious e-scape rooms are theoretically well-positioned to offer enjoyable, deep and meaningful e-learning experiences for various playing styles and learning preferences [29]. In the next sections we present our effort to apply the model and test the validity of the above theoretical assumptions.

IV. Case Study: The Room of Keys

The serious e-scape room "Room of Keys: A lesson on enzymes" (see Fig. 1) was built as a proof of concept to examine if a game-like VR experience can affect students' learning approach, motivation and performance.

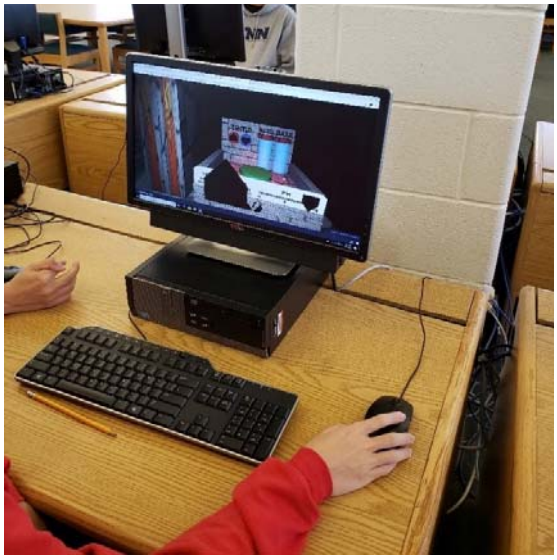

Fig. 1. A student playing the "Room of Keys" serious e-scape room at a desktop computer in the library

A. Pedagogical Design

The material covers the biology curriculum standard Bio.4.1.3 as defined by the North Carolina Department of Public Instruction [30]: "Develop a cause and effect model for specificity of enzymes - the folding produces a 3-D shape that is linked to the protein function, enzymes are proteins that speed up chemical reactions (catalysts) by lowering the activation energy, are re-usable and specific, and are affected by such factors as pH and temperature."

This topic appeared especially fitting since enzymes operate as "keys" in chemical reactions and thus constitute a perfect metaphor in a breakout activity. The Room of Keys challenges users to be observant and unlock information about enzymes, then use that information to solve puzzles and challenges on the way to escaping the virtual room.

B. Game Design

The game is broken up into an introductory/tutorial phase, an expositional experience, which conveys the necessary content, and finally a set of puzzles or challenges that can be solved through the application of the knowledge from the previous phase. The information necessary to solve the latter puzzles, which is presented during the expositional phase, stays under display for the entire experience. This allows the player to go back and review as necessary to solve the puzzles. To allow flexibility in exploration, we chose not to introduce a time limit in which the activity must completed.

The introductory phase is composed of a series of panels that form a pseudo-room around the user when he/she begins the game. The panels instruct the user in how to look around and interact with objects and the environment, how to move around the space and the general goals of the game.

The next, expositional phase is composed of a set of five flying keys, each labeled with an icon. After a brief mini-game that involves knocking down and collecting the keys, the user

can then unlock panels of information relevant to enzymes. The information is presented both visually and through audio to cover different learner types (see Fig. 2).

There are icons that correspond to each of the five "chunks" or sections of information that the material is broken up into. The activities are marked with the icons that correspond to the information necessary to solve it. This is to make it easier for the player to find the necessary clues in the information to solve the puzzles in the next levels.

After all five panels are revealed, the first puzzle unfolds. To complete the level, as is the case with all puzzles, the user must apply the information from the expositional phase. In this first challenge, the user must use both the knowledge that enzymes are a protein, from the general enzyme information panel, and that proteins are identified using Biuret solution, from the Indicators panel. This reveals two new keys, one of which opens the way to the next level.

The activities that follow continue to challenge the user to apply the information in realistic, simulated contexts. For example, in the denature activity the user is presented with a warped shape representing an enzyme, which is contained in a large vat that has controls for temperature and pH. In the denature panel the user is informed of how enzymes only retain their shape under normal temperature and pH conditions. Otherwise, they lose their normal shape and become denatured, and therefore cannot work since they no longer fit in their substrate. The user can alter the temperature and pH in the vat using buttons and levers, which in turn changes the shape of the enzyme. Once both of those variables reach the optimal conditions, the user is given feedback that they were successful, and the enzyme appears in the user's HUD. This enzyme in turn can then be used on the next level challenge, which simulates a synthesis reaction. The enzyme the user just picked up is placed in a translucent placeholder that matches that shape and begins a chain reaction where steps meld together to form a staircase that allows the user to reach the key to the next activity. This process further models enzymatic activity by showing how the enzyme initiates and takes part of the reaction, but that it is not consumed in the process.

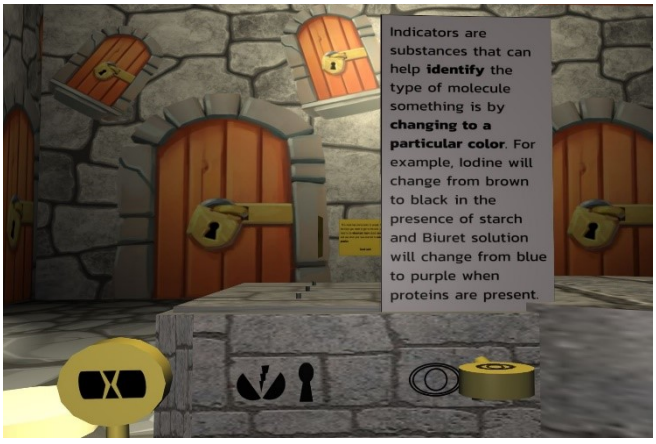

Fig. 2. The expositional phase of the gaming experience

Puzzles in each subsequent level increase in complexity and difficulty. These simulated activities challenge learners to reflect on the content and solve the puzzles, as well as exemplify and model key concepts of the content being used and thus develop deep understanding of the concepts and construct higher order thinking skills [31]. The game was developed in collaboration with a local librarian, Natalie Strange, who was experienced in constructing physical escape rooms, as well as Jessica Tidmore, a local Biology teacher. The game was deployed at the library using their desktop computers and Ms. Tidmore's current Biology class students.

C. Development

"Room of Keys" was developed in the Amazon Sumerian platform. This platform was chosen for its affordability, ease of access and low learning curve. The platform is appropriate for educators without a programming background for developing device-agnostic and mobile-device friendly applications and experiences. It is also capable of developing VR and AR experiences.

The platform, and any experiences built in Sumerian, are cloud based. There are no purchase fee or downloads required to work in it, or to play the application. There is also a minimal cost model based on the number of users that play the experience. To distribute a build, one simply shares the URL after publishing it. Anyone with that link can then access it from any browser.

V. Evaluation Process

To evaluate the model, we conducted a mixed exploratory pilot study combining quantitative and qualitative methods [32]. This approach was preferred in our effort to explore in depth and build consensus of the intervention's effect. Our data collection methods were pre- and post-test questionnaires that tested the deep understanding of the learned content and oral feedback from students. We hypothesized that (1) there would be a significant knowledge increase in test performance and (2) students would enjoy the experience and increase their motivation.

A. Procedure

148 students at Northwest Guilford High School in North Carolina, USA played the beta version of the "Room of Keys". The students were given a pre- and post-test at the same day, immediately before and after playing the game. Most of the participating students were between 14 and 16 years of age, while there was an almost equal representation between males and females with 71 male, 72 female, and 5 students choosing not to identify a gender. Students played the game on desktop PCs at the school library between January and February 2019.

B. Instruments

The pre-test contained four demographics questions and eight closed, multiple-choice items regarding the game content and outcomes. The post-test was comprised of the same eight assessment questions and seven evaluation items on user experience and perceptions; six closed and an open question item. The closed evaluation questions used a five-point Likert scale where students expressed their degree of agreement or disagreement with the particular statement. Both tests were eponymous. The tests were created and administered electronically using Google Apps for Education.

The eight closed, multi-choice assessment questions in both pre- and post-tests were the following:

1) Which characteristic is MOST LIKELY true for enzymes in the human body?

2) Why is the "lock and key" analogy often used to describe enzyme function?

3) Humans can use starch as an energy source, but are unable to use cellulose for energy. Which of the following BEST explains the difference in how these molecules are processed in the body?

4) To which class of organic compounds do enzymes belong?

5) Many people are lactose intolerant and cannot digest dairy products. What enzyme are their bodies MOST LIKELY lacking?

6) Sucrase, an enzyme, is added to a solution containing water and sucrose. Which variable would change?

7) How does an enzyme speed up chemical reactions?

*8) *How is the role of enzymes in biochemical activity BEST explained?*

VI. Results

148 students completed the pre-test and 143 of those students completed the post-test, with 5 students failing to do the post-test after completing the activity. The average activity completion time was 15 minutes. 90.2% of the students reported that they had been already taught the game's content, enzymes, during their Biology class. Total possible points on the evaluation was 7 points, one point being awarded for each correct answer. The last question (8) was excluded from the data analysis because its formulation didn't have one, definitive correct answer.

A. Student performance

Student performance between pre- and post-test improved by 13.8% as was evidenced by the distribution of students scoring higher on the examination. The pre- and post-test results are illustrated in Fig. 3 and 4. There was an increase for all but one of the questions, which saw a decrease and would bear closer examination. Two questions were answered correctly significantly more with a 20% or greater increase in incidence of correct answers. Student's performance in each assessment item is depicted in Table 1 and Fig. 5. This finding is consisted with students' subjective sentiment that played the game increased their understanding and performance (see Table 2).

Fig. 3 Pre-test Score Distribution

Fig. 4 Post test score distribution

B. User Experience and Satisfaction

The results of the user experience evaluation results are summarized in Table 2. The subsequent feedback revealed that students generally enjoyed the game and playing increased their knowledge and motivation albeit facing some technical challenges. Some of the specific written and oral comments of learners on the game were the following:

"I thought it was fun to play"

"I have no thoughts or suggestions about the game. It was well put together and enjoyable. I only got confused once, but after I understood what I was trying to do, I was able to complete the task! :)"

"When's the 3rd one coming out!?!?!?!?!?!?!?!?!?!?!?"

"This should be played during/before the students learn about enzymes, not months later. It is somewhat okay to use a review tool."

"Make it longer and harder."

"It was simple and had good notes with it. It is also easy learning."

In the post-test section on experience evaluation, learners were also asked the following questions; "Do you feel like this game could be used in a classroom to help teach students about enzymes?" and "Do you feel like this game could be used in a classroom to help reinforce students understanding about enzymes?" to which students answered yes 85% and 88% of the time, correspondingly.

Another finding of the evaluation was the need to improve the game instructions and more specifically player movement. Several students expected to be able to move in the virtual environment using the keyboard's arrow keys. Instead they had to click on specific spots on the ground to move around. This decision was made to accommodate full compatibility with players wearing VR headsets. As a result, students faced initially technical difficulties navigating the environment and playing the game. Another factor that could have lead to this phenomenon in this pilot study was the absence of teachers or other personnel to answer student questions or address technical problems. Here are some indicative comments:

"Although the game is supposed to be fun it is difficult to figure out the mechanics, but once you figure them out the game is pretty easy. Just maybe explain that the game is a point-and-click game."

"You need to have a teacher in the room that can explain if students need help."

"I was confused about how to move until i realized it was the dots on the ground."

We responded to the feedback by providing printed instructions in a hand-out and by adding instructional panels with elaborated game instructions in the virtual environments that players see at the very start of the game.

Overall, students enjoyed the game, developed a deeper understanding the concepts, and increased their interest in biology as demonstrated by their comments and performance increases as well as observations by Mrs. Strange and Ms. Tidmore, included below:

"The virtual environment was key in allowing students to experiment with enzymes and pH factors in ways that are

difficult in a standard high school lab. The program encourages students to think beyond rote learning and move into application through experimentation." – Natalie Strange, Librarian

"The kids really enjoyed being in the computer lab and working on the escape room. They do struggle with puzzles because they don't know how to be critical thinkers, so I really enjoyed this experience in helping the students realize that puzzles can be fun and educational." – Jessica Tidmore, Biology teacher

Results overall confirmed both hypotheses.

TABLE I. PERCENTAGE OF CORRECT PRE- AND POST-TESTS ANSWERS

Question	Pre-Test	Post-Test	Change
1	52.03%	72.03%	20.00%
2	78.38%	87.41%	9.03%
3	72.97%	76.92%	3.95%
4	73.65%	80.42%	6.77%
5	95.27%	96.50%	1.23%
6	10.14%	6.29%	-3.84%
7	45.27%	67.13%	21.86%

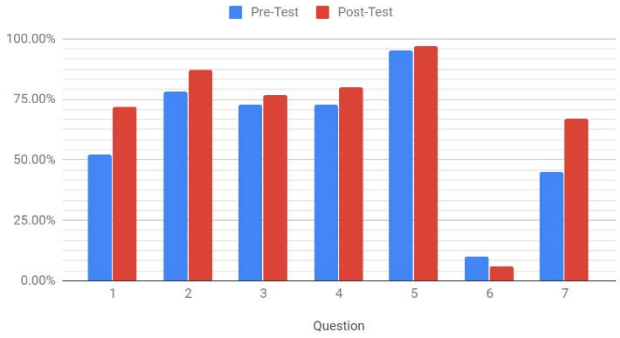

Fig. 5 Summary of incidence of correct answers in the pre- and post-tests

TABLE II. GAME EVALUATION

Question	Average	St. Dev.
How did you like the Room of Keys?	3.59	1.17
Do you feel like this game helped you learn about enzymes?	3.15	1.19
Was the game easy to understand?	3.03	1.32
Do you feel that you answered more questions correctly after playing the game?	3.55	1.02
Do you feel like this game could be used in a classroom to help teach students about enzymes?	85.3% (Yes)	
Do you feel like this game could be used in a classroom to help reinforce students understanding about enzymes?	88.1% (Yes)	

VII. CONCLUSION AND FUTURE RESEARCH

In this paper we present a new and cost-effective model for designing serious games in virtual reality environments for deep and meaningful learning, a virtual escape room. We provide the general guidelines and principles for the design and development of such experiences. We present also the process and the positive results of the application of the proposed model to the "Room of Keys" virtual escape room. Playing the game improved significantly high school students' understanding, despite the fact that the topic was taught and supposedly already known to them. The pilot study revealed important findings that will guide the improvement of the user interface and experience. The proposed Serious E-scape room model can be beneficial both for educators and VR developers. Educators can use creatively the established, popular yet fully customizable template of escape rooms to develop virtual immersive experiences that engage learners. Similarly, VR developers can partner with subject-matter experts and deliver robust, compelling and scalable serious games that demonstrate the immersive affordances of VR platforms for education.

In the future, we intend to improve the game based on user feedback and conduct experiments to study the learning quality and effectiveness of the experience also in adult audiences such as higher education students. Also, we want to further develop the model to assist practitioners from all fields to design and develop smart VR learning experiences that share their passion and create excitement that leads to durable, deep and meaningful learning.

ACKNOWLEDGMENTS

Special thanks to Northwest Guilford High School for allowing us to deploy this activity. Also to Jessica Tidmore for her knowledge of the content, for allowing her classes to take the activity and for preparing the pre and post assessments. And also to Natalie Strange for providing her understanding of escape room design, the space and computers at her library, and her continued insight and wisdom. Finally, special thanks to Randy Hinrichs for being a mentor and global hub for educational innovation in 3d virtual immersive environments and beyond.

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