Teaching Programming Courses with Digital Educational Escape Rooms (DEER): A Conceptual Proposal Conducive to Learning by Trial and Error

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Abstract

In the field of programming education, the advent of new technologies such as ChatGPT has reshaped the landscape, challenging traditional methods and requiring new approaches to engage students effectively. Conventional teaching techniques find it hard to compete in a world where digital requests with instant feedback are plentiful. This shift emphasises the importance of innovative strategies, such as educational digital escape rooms, in programming education. By taking advantage of immersive storytelling and interactive challenges, these digital environments captivate students' interest and facilitate active learning. Instead of passively consuming information, students have the ability to apply programming concepts in a dynamic and gamified environment, promoting a deeper understanding and retention of the concepts. This paper presents a first effort in a work in progress to build an educational platform based on the digital escape room concept to be used in the classroom (or at home) throughout the school term.

2012 ACM Subject Classification Applied computing → Interactive learning environments; Software and its engineering → General programming languages

Keywords and phrases Education, University, Programming, Serious Games, Escape Rooms, Gamification

Digital Object Identifier 10.4230/OASIcs.ICPEC.2024.9

Funding This research was funded by Portuguese national funds through FCT – Fundação para a Ciência e Tecnologia, under the project UIDB/05422/2020.

1 Introduction

In recent years, the ability of students to concentrate in the classroom, either listening or doing practical problems, has diminished considerably, and it has become increasingly difficult to convey the concepts that are essential to their learning, especially in the first years of bachelor's programmes. From an early age, they get used to having the answers almost immediately, thanks to electronic devices, not giving them the opportunity for real learning (reflection and critical thinking), worrying only about the results. The emergence of artificial intelligence (AI) tools such as ChatGPT has made the process even more difficult, as they feel they can solve everything with such a tool and that the knowledge is all there. Although this is partly true, they have overlooked the necessity of having someone, specifically the teacher, to pose the questions that need answers and to develop a structured plan for their learning. Thus, the inability to keep students engaged and focused during lessons makes it urgent to look for innovative and motivating alternatives. In this context, gamified

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or game-based teaching, with an emphasis on "digital escape rooms", has emerged as a promising tool for overcoming the challenges of contemporary education. This dynamic and immersive approach offers a stimulating and engaging learning environment, capable of capturing and maintaining the attention of students, even those with greater difficulty concentrating. Digital educational escape rooms (DEER) simulate challenging scenarios that require students to solve puzzles, use logical reasoning and collaborate as a team to achieve a common goal [6, 5, 7]. Through the inclusion of gaming elements, this methodology transforms learning into a fun and rewarding experience, awakening students' interest in programming in a natural and organic way. Instead of feeling pressurised by deadlines and rigid objectives, students are encouraged to explore, experiment and make mistakes without fear, in a safe environment conducive to learning by trial and error. This autonomy and freedom of action contributes to the development of creativity, problem-solving and critical thinking, essential skills for success in the digital age [4, 8]. In addition, game-oriented methods using DEER promotes social interaction and teamwork, fundamental elements in the formation of complete citizens prepared for the challenges of the labour market. Students learn to collaborate with each other, communicate their ideas effectively and deal with different perspectives, essential skills for success in any professional field.

The challenges in creating DEER are, on the one hand, to ensure that they cover the learning and assessment of all the skills in a course unit, such as programming, and, on the other hand, the difficulty of constantly creating challenges/inventive games for students that don't fall back on what they already know. In this paper we present a structuring proposal with examples for teaching programming through DEER.

2 Literature review

Using the search expression *(TITLE-ABS-KEY (escape PRE/0 room* AND (virtual OR digital) AND education*)) AND (LIMIT-TO (SUBJAREA , 'COMP') OR LIMIT-TO (SUBJAREA , 'ENGI'))* in SCOPUS, limited to the areas of "Computer Science" and "Engineering", 91 articles were obtained, as shown in Figure 1, where it is possible to verify the growing popularity of the topic in recent years.

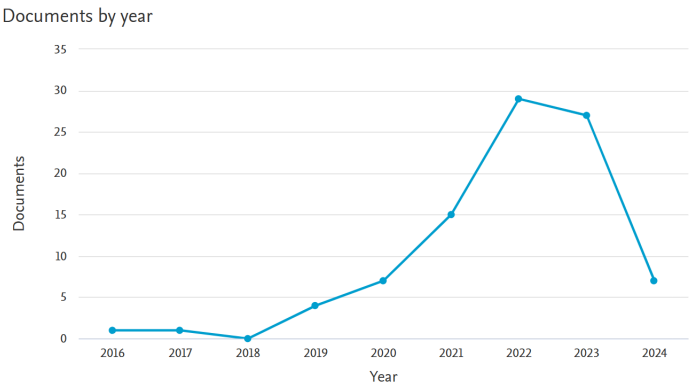

Figure 1 Search result in scopus database relative to DEER (april 2024).

From the list of articles retrieved from the search, we selected those accessible through our institution's SCOPUS subscription that included concrete examples of DEER implementation, aiming to identify methodologies and technologies useful for the design and development of our proposal. The studies are presented in the order in which they appeared in SCOPUS, with a summary of the most relevant aspects for our proposal at the end.

The first work analysed presents the concepts involved in developing an escape room for teaching International Business [6]. The Escape Room creation involves defining learning objectives, developing a storyline, selecting game duration and language, creating challenges, designing clues, and testing the scenario. The authors based the development of their project on the AIDA model (Attention, Interest, Desire, Action). With regard to the technologies used to create the escape room, they used Genial.ly and Google Forms. According to the authors, the students were able to complete the game, with the students emphasising the need for teamwork in order to successfully complete the game.

As part of the German government's "Education in the Digital World" strategy, a DEER was created for the promotion and transmission of associated content in a playful way [4]. In this project, a digital serious game was designed and developed in a 2D environment, where various interactive elements, tasks and puzzles were incorporated into a digital educational Escape Room. The tests and evaluations carried out on the students afterwards showed a notable increase in their motivation and demonstrated their ability to solve tasks requiring the necessary skills.

In the work [8], the authors propose the use of DEER in STEAM (science, technology, engineering, arts and maths) education. They highlight the potential of DEER as a pedagogical tool to promote active learning and increase student engagement in STEAM education. To produce DEER, they propose a seven-step methodology: 1) Identify learning objectives: Understand what knowledge and skills students need to acquire; 2) Choose the platform: Select a digital escape room platform that suits your objectives; 3) Create a storyline and theme: Devise a narrative that engages the students and aligns with the objectives; 4) Design puzzles and challenges: Develop challenges that stimulate critical thinking without frustration; 5) Chart the learning path: Plan a sequence of puzzles that lead to achieving the learning objectives; 6) Incorporate feedback: Provide hints or clues to keep students engaged without giving away the solutions; 7) Test and Evaluate: Evaluate effectiveness with a test group to refine and improve the experience. In their work, they identified the following patterns for developing escape rooms: 1) Search and find: Players look for clues and objects within a room to solve puzzles and advance; 2) Lock and key: Players find keys or combinations to open doors or containers that hold essential items; 3) Observation and deduction: Players use visual and audio clues to solve puzzles through careful observation and deduction; 4) Sequence and order: Players must determine the correct sequence of actions or the order in which to solve the puzzle; 5) Communication and collaboration: Players work together, communicating effectively to solve the puzzles; and 6) Misleading clues: Misleading clues divert players' attention from the real solution, increasing complexity. With regard to technologies they identified the use of Breakout EDU, Escape Classroom, EdPuzzle, and Gdevelop. The authors found that 91.2% of students who responded to the questionnaire indicated that it enhanced their comprehension of the subject matter.

The work of [12] examines the use of DEER for teaching calculus as part of the engineering curriculum at a university in Spain, carried out entirely online. The Genial.ly platform was used to develop DEER. The authors conclude that incorporating DEER into calculus teching in engineering proves to be an effective tool in engineering education. In particular, student satisfaction with the experience was remarkably high, with a significant demand for similar learning opportunities in the future. Another project that used the Genial.ly platform was [1], which designed DEER with the aim of preparing and revising the concepts and topics of the subject before the final exam. Not many details are given about the design of DEER, but the document does give examples of DEER. The students' opinions on the experience were mostly positive, so the activity can be used to motivate interaction in an online course.

[7] work focuses on the development of DEER by 65 university students to be used by first graders. Forty-one DEER were created using the Design-Based Research methodology for different teaching areas: History, Grammar, English, Geography, Science and Maths. Although the authors have not provided a guide for designing DEER, they are very concerned with the learning objectives vs. the playfulness of the game (educational design vs. game design), in other words with designing effective DEER. The authors conclude that DEER provide innovative learning environments that cultivate thinking skills and social competences. Maintaining a balance between game design and learning design during development is crucial to maximising the relevance of DEER.

[3] present a platform developed with the Unity game engine for escape rooms based on virtual reality (VR) for teaching programming, which they consider to be a promising solution for improving students' results and motivation, allowing them to develop skills such as practical knowledge, creativity, and problem-solving skills. The fact that it's multiplayer encourages collaboration, enriching the learning experience. The platform allows the creation of escape rooms with different types of puzzle (hort answer, multiple choice, and jigsaw puzzles) for students to use, thus promoting problem-solving and critical thinking. The initial findings indicate that students exhibit a markedly positive attitude towards our VR-based DEER platform. Within the topic of VR-based DEER development, some works were found, such as [10, 9, 11], many of them more advanced than the work of [3], also including gamification concepts in the platforms [9, 11]. VR-based DEER are seen as the solution of the future for implementing DEER, since they allow interaction between the different players in the game itself and are therefore truly immersive, whereas many DEER proposals do not allow such interaction.

The work by [5] differs from the previous ones in that the authors focus mainly on the learning assessment process. As they point out in their own work and as we can also confirm, most of the studies we've come across focus a lot on the design and implementation of DEER but don't delve much into the assessment of learning, mostly presenting questionnaires answered by students about their level of satisfaction with DEER, lacking a more rigorous assessment of learning. Based on this assumption, the authors propose using learning analytics techniques to evaluate learning. In particular, they took advantage of new developments in sequencemining methods to analyse the temporal and sequential patterns of the actions performed by the students during the activity. In addition, they use clustering to identify different player profiles according to the sequential unfolding of the students' actions and analyse their acquisition of knowledge. The study was carried out as part of an undergraduate course on front-end programming at the Polytechnic University of Madrid. A DEER activity was implemented as an optional reinforcement exercise to solidify the fundamental concepts taught in a core segment of the course. These concepts encompassed the basics of HTML, CSS, and JavaScript, as well as more advanced technologies like React, Redux, and React Native. Students were paired up based on their own preferences, enabling them to benefit from collaborative learning and the advantages of pair programming. A total of 96 students participated in the study, organized into teams of two. When encountering difficulties with solving the various puzzles, students were permitted to request hints from a predefined set prepared by the instructors. However, to access these hints, students first had to earn them by successfully completing a brief online quiz covering the theoretical content of the course. This quiz served as a complement to the practical programming skills targeted by the escape room activity, enhancing the overall learning experience.

3 DEER Conceptual Proposal

The literature review showed that there are already many experiments underway in the use of DEER using different technologies. One of the most notable technologies is the trend toward using virtual reality to develop more advanced DEER, enabling players to interact with each other within the DEER environment. Many of these experiences are presented as small experiments to be used as a complement to teaching. We didn't find any experiments that lasted an entire school term, i.e. in which lessons were given with constant recourse to this type of platform, which is something we're trying to implement, given young people's receptiveness to this type of solution. In the literature review, it was possible to see the concern with defining the objectives/competences to be acquired by the students and, in the latest work presented [5], the concern with assessing learning. Figure 2 shows our proposed workflow for the implementation of DEER lasting one school term, which follows the traditional phases of the ADDIE model [2]: Analysis, Design, Development, Implementation and Evaluation.

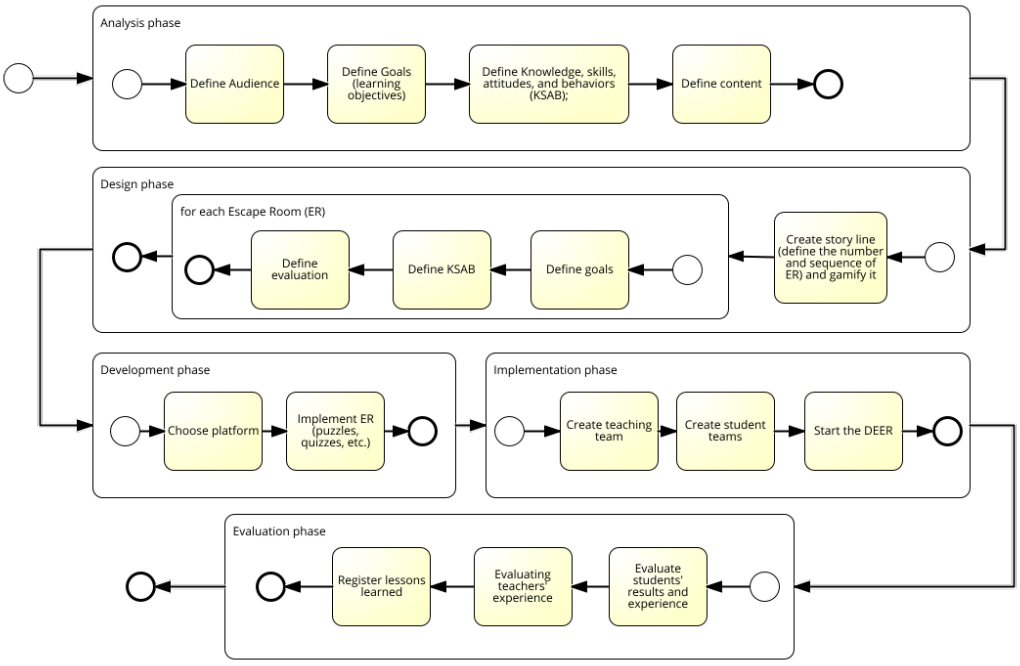

Figure 2 DEER conceptual proposal.

The model presented in Figure 2 outlines the stages for creating a DEER. The model does not include the technologies (virtual reality, generative AI, etc.), types of escape rooms, or how student learning control, including gamification should be implemented, as these depend on the choices of those implementing the DEER. Nonetheless, all the necessary stages for implementing a DEER are clearly outlined. Nonetheless, the model outlines all the stages and requisite elements, drawn from the literature review, for implementing effective and efficient DEER to bolster student learning. During the analysis phase, alongside delineating objectives, it is imperative to specify the Knowledge, Skills, Attitudes, and Behaviors (KSAB) students are expected to attain and how their acquisition will be assessed throughout the design and implementation phases. Furthermore, apart from acquiring the KSAB, it is crucial

to solicit feedback on students' experiences by conducting a satisfaction questionnaire or evaluation of the entire process upon its conclusion, a practice already commonplace in both physical and virtual curricular units.

4 Examples of escape rooms

In this section we present two possible challenges that could be included in the implementation of escape rooms, in this case for teaching Python programming.

Challenge 1: Title: "Numbers and codes"

- Puzzle Description:
  - Look at the Python script and execute the correct sequence of actions to unlock the door and escape the room.
  - To escape the room, you'll have to go through all the stages.
- Hints
  - Pay attention to the comments within the script. They provide clues on what to do at each stage.
  - Think logically about how Python functions and code blocks work.

Listing 1 Challenge 1 Code.

```
def stage_one():
    print("Stage One!")
    roman_num = "MMD"
    # Insert code
    print("The arabic number is: 2500")
    print("Congratulations! Proceed to stage two.")
def stage_two():
    print("Stage Two!")
    print("You're presented with a sequence of numbers.")
    sequence = [2, 1, 1, 2, 3, 5, 8, 13, 21, 34]
    # Insert code to perform operations on the sequence
    print("The transformed sequence: [4, 2, 2, 4, 6, 10, 16, 26, 42, 68]")
    print("Congratulations! Proceed to stage three.")
def final_three():
    print("Stage Three!")
    print("You face a formidable challenge: the Enigma code machine.")
    enigma_message = "JXHFUJ WTTR XZHHJXX! BJQQ ITSJ!"
    # Insert code to decrypt the Enigma message using Python
    print("The Enigma message is decrypted:" +
        " 'ESCAPE ROOM SUCCESS! WELL DONE!'")
    print("The door unlocks, and you've successfully escaped the room.")
def main():
    print("Python Codebreaker Challenge: Decrypt the Enigma")
    # Insert code to call up the different stages in order
```

Challenge 2: Title: "Pick a number?"

In this second example, only an image is presented because the idea is for the readers of this article, like the students, to try to find a solution to the challenge. If you need a hint, please contact the article's first author.

Figure 3 Pick a number challenge.

5 Conclusion

The work presented in this paper endeavors to address a significant contemporary trend in education, namely the diminishing ability of students to concentrate in the classroom. This trend is attributed in part to the prevalent use of electronic devices and AI tools like ChatGPT, which provide immediate answers and discourage deeper reflection and critical thinking. Consequently, educators face increasing difficulty in effectively conveying essential concepts, particularly in the foundational years of bachelor's programs. In response to this challenge, this work explores the potential of game-based teaching, with a focus on DEER, as an innovative and engaging alternative, as can be seen from the literature carried out. DEER offers a dynamic and immersive learning environment that captures students' attention and fosters essential skills such as problem-solving and teamwork.

However, the implementation of DEER poses its own set of challenges, including ensuring comprehensive coverage of learning objectives and maintaining student engagement with varied and inventive challenges. Despite these obstacles, the paper presents a conceptual proposal, which needs to be tested and improved, for teaching programming through DEER drawing on existing literature and emphasizing the importance of clearly defined learning objectives, ongoing assessment, and feedback mechanisms.

Ultimately, the paper advocates for the integration of innovative teaching methodologies like DEER to meet the evolving demands of contemporary education.

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