Enhancing Algorithmic Thinking Skills through Phygital Games: The Case of Space Codyssey

Sotirios Georgiou and Tharrenos Bratitsis
University of Western Macedonia, Florina, Greece
dnured00136@uowm.gr
bratitsis@uowm.gr

Abstract: This paper presents an educational phygital game, Space Codyssey, aiming at cultivating the algorithmic thinking skills of young children. Space Codyssey is a phygital game, and its contains programming activities for the Sequence, Repetition, and Selection Structures, as well as Code Debugging activities (Debugging). The game utilizes Augmented Reality technology to present missions via QR cards. Additionally, digital storytelling is used as a means of assistance and teaching for preschool and early primary students. In the game, reading skills are not a prerequisite, and programming is accomplished using symbolic commands through a "Visual Programming Language." The participatory design methodology that was adopted, involving 28 educators from various specialties, reflects a holistic approach to the development of educational technologies. This interdisciplinary collaboration allowed for the integration of diverse pedagogical perspectives, ensuring that the game meets the multifaceted needs of modern education. The paper highlights the educational goals and learning outcomes for the designtated age group. It presents the scenario, the subject, the elements of the game, the rules, and the game mechanics. It also describes the implementation stages and the development of the application. Finally, it presents the results from a study, which involved 28 educators and aimed to improve the game before its use in educational settings.

Keywords: educational board games, computational thinking, augmented reality, digital storytelling, primary school

1. Introduction

Understanding algorithmic structures is a fundamental skill in the digital era, of growing importance for child education beginning from the preschool age. Algorithmic structures are the basis of computational thinking and programming while fostering the development of logical thinking and problem-solving (Wing, 2006).

Integrating the algorithmic structure teaching in preschool and primary education has multiple benefits. However, teaching algorithmic structures in such early ages is a challenging task. Careful planning of instructional activities is required so that they are appropriate for children's developmental level and keep their interest high (Fessakis et al., 2013). Moreover, it is critical to both avoid overemphasis on technology and preserve a balance with other essential aspects of children's development (Bers, 2018).

Learning through play is a powerful educational approach, especially for children of this age. Board games, in particular, offer a unique framework for developing a variety of skills and reinforcing learning in a fun and engaging way (Bratitsis et al. 2023, Tsapara et al. 2023).

Research shows that board games can contribute significantly to the development of cognitive, social, and emotional skills. According to Cleto et al. (2019), the use of physical and virtual objects in hybrid games can enhance learning of key programming concepts. This is supported by Jin et al. (2018), who developed a tangible programming tool that uses augmented reality technology to boost children's computational thinking.

The need to create a board game like Space Codyssey that works in conjunction with a smart device arises from the increasing importance of computational thinking and programming skills in modern education. The game offers a unique approach to learning basic algorithmic structures by combining the advantages of traditional board games with Augmented Reality (AR) technology. This combination creates an environment that bridges the real and digital worlds, helping children to better understand abstract programming concepts. The game is presented in the next section. Then the results from an assessment study, involving 28 educators is presented before the concluding discussion.

2. Game description

Space Codyssey, with its combination of physical and digital elements, offers an inclusive approach that can cover this need engagingly and appropriately for the target age group.

2.1 Introduction

The basic goal for players is to learn basic programming and computational thinking principles through a fun and interactive game. This is achieved by "visualizing" and "clarifying" the creation of algorithms to solve problems.

2.2 Learning outcomes:

- Understanding of basic algorithmic structures
- Development of programming logic
- Improving debugging skills
- Strengthening spatial perception

2.3 Game design

The game story script is that the players are lost in the universe and are looking for a habitable planet to colonize. But to do this they have to pass through other planets and solve activities (by programming) that will give them fuel to keep going. The game includes a 30-point track up to the finish line, 28 cards measuring 7cm x 8xm, divided by color, 6 red, 6 green, 6 blue, 6 orange, and 4 black. 6 14cm x 9cm programming explanation cards and spaceship-shaped pawns (Figure 1).

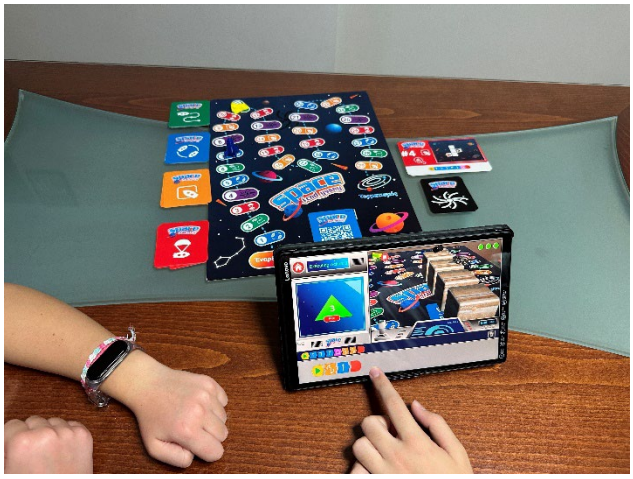

Figure 1. The board game and the corresponding mobile application

2.3.1 Game rules

The game rules are simple as it addresses the needs of children 5 years old and above. The first player who gets the highest number on the digital pyramid dice starts the game. At each position on the track, there are some actions to be carried out. The player who reaches the finish line (galaxy) first is the winner.

2.3.2 Game mechanics

The player depending on the number on the dice, moves the spaceship across the spots on the tableu. All positions are colored and thus when reaching them the player has to pick a corresponding colored card. The cards are divided into colored categories: Green cards for Sequence Structure activities; Blue cars for Repetition Structure activities and the Orange ones cards for Choice Structure activities. All the cards incorporate a QR code on one side. By scanning it displays the activity the player has to carry out in a 3D form quiz/puzzle. Correct solution of the puzzle leads the spaceship to fuel and the player can proceed during the next turn. Failing to solve the puzzle requires that the player stays on the same spot, selecting a new card in the next turn. The Red cards incorporate numbers and when scanned display a robot assistant who PROVIDES audio instructions for program debugging (cards with incorrect codes). Additionally the robot assistant helps players understand basic principles of computational thinking.

2.3.3 Technological implementation

Unity3D (Figure 2) is particularly well-suited for serious game development due to its flexibility and powerful engine, which allows for the creation of high-quality 3D environments and the integration of advanced features. In addition, the platform can create applications for PC and mobile devices with VR/AR technologies. The Vuforia SDK was selected for developing the AR material, as it is considered one of the best choices for "cross-platform" (Android, iOS) applications. For the game, cards with QR codes were designed, which when scanned by Vuforia's recognition engine, display the missions that the player must solve to get fuel and continue.

A "Visual Programming Language" was also designed. This language "runs" through the application and works cooperatively with the 3D graphics so that if the player designs the code correctly, the activity is solved fuels is received. This language relies on graphics and visual representations instead of text. Programming commands are presented as puzzle pieces with specific symbols that users can drag and place to build a program. This type

of programming is suitable for young children, as it reduces code complexity and promotes understanding of basic programming concepts.

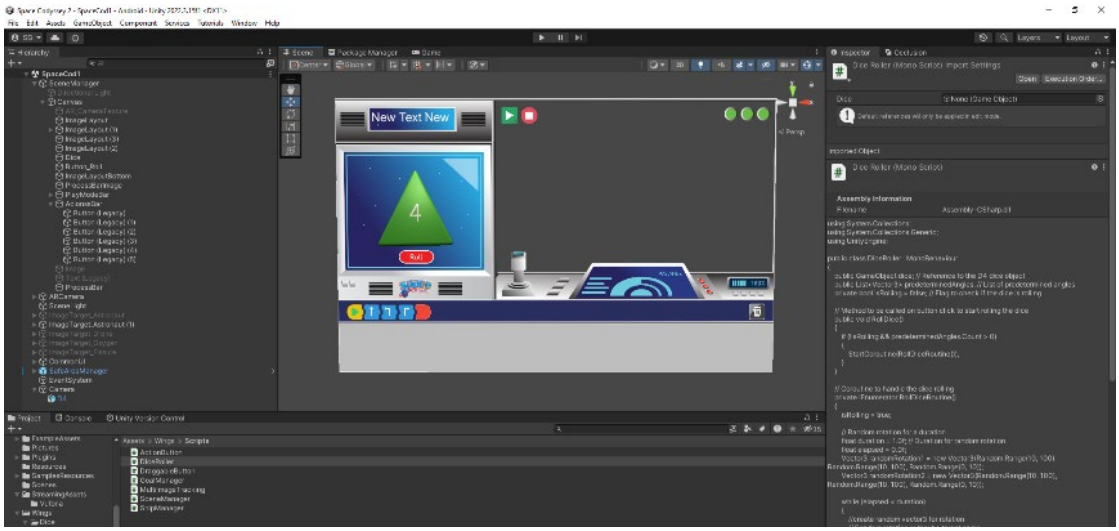

Figure 2 Developing the application on Unity3d

The design and development stages of Space Codyssey reflect an evolving process, adjusted to the needs and characteristics of preschool and primary school children. The game track was transformed from a simple flowchart to a living, space-based landscape. The graphics were enriched with bright colors and child-friendly characters, while the cards and images were designed with bright, cheerful patterns to attract young players. Each element was designed with visual clarity and ease of use in mind, allowing children to focus on the learning process. Particular attention was paid to the clear delineation of the different functional areas of the application. The pyramid dice area, the governance (camera) screen and the programming area have been designed to be clearly visible. This visual separation helps players quickly understand the function of each part of the app, thus improving the overall user and learning experience.

3. Participatory design, pilot testing, and reviews

The development of the game followed an itterative approach, with five consecutive trial versions, each of which was subject to strict evaluation and optimization based on teacher feedback.

The participating teacher sample is characterized by a high degree of interdisciplinarity, consisting of 28 primary school teachers. Their contribution to the development of the game was made through semi-structured interviews, initial concept presentations, and different versions of practical testing.

A detailed interview protocol was designed and followed that covers various aspects of the game, from its design and implementation to its educational value. The categories of questions are as follows:

- Introductory questions
- Implementation of the physical elements of the game
- Appearance and functionality of the application
- Combined QR code card function with Augmented Reality and Digital Storytelling
- Educational benefits
- Improvement proposals

This multi-dimensional approach to design ensured Space Codyssey pedagogical suitability and educational efficacy in a variety of educational settings. The synergy between different specialties contributed to the creation of a holistic educational tool that integrates best practices from different areas of education and computer science teaching.

The key findings from the teacher interviews focused on the following areas:

- Improving the direct interaction between QR code cards and the Vuforia SDK engine, as well as enhancing the visual presentation of activities.
- Adjusting the 3D graphics to make the planet's positions clearer. This involved changing from spherical to cubic representations to help students better understand the steps.

- Teachers suggested using a smaller die with numbers only up to 4. This suggestion was based on the observation that young students might struggle with larger numbers and that the limited number of spaces on the game board didn't require larger numbers. The design team adopted this change, which is expected to make the game more accessible to young players and improve game flow.
- Educators recommended refining the robot's audio instructions to make the concept of debugging easier for students to understand. This suggestion arose from observations that younger students often struggled with the abstract nature of debugging in programming.

4. Future plans

The next important step in the game development is the application. A study will be carried out on a sample of 5 to 9-year-old pupils in educational institutions in the region of Western Macedonia, Greece. The methodology entails the use of pre-experimental and post-experimental tests, specifically designed to assess the understanding of basic algorithmic structures. This approach allows the collection of quantitative data to measure the effectiveness of the software as an educational tool. The results of the study will undergo statistical analysis to identify the statistical significance of the observed learning outcomes. The findings are expected to provide empirical data on Space Codyssey effectiveness and lead to software future improvements. It is to be noted that Space Codyssey was designed for the needs of a doctoral thesis.

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