Educational Video Game for Learning Binary Search Tree

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Abstract. This demo paper presents two prototypes of an educational video game for learning Binary Search Tree data structure in higher education environments. The prototypes were used to evaluate the effectiveness of video games to teach abstract non-intuitive conceptual knowledge and the effect of educational video games' perceptual realism on learning gains and motivation. The paper provides a detailed description of the game, focusing on the game's learning aspects, such as the learning theory, pedagogical approach, learning objectives, and learning activities. It also emphasizes how the game elements reflect the learning aspects to facilitate learning complex conceptual knowledge.

Keywords: Analogies · Educational Video Game · Binary Search Tree

1 Introduction

In this demo paper, we present two prototypes of an educational video game, *DS-Hacker*, designed for learning the Binary Search Tree (BST) data structure in higher education environments. The game aims to evaluate two aspects: (1) the effectiveness of video games in teaching abstract, non-intuitive conceptual knowledge, and (2) the impact of video games' perceptual realism on learning outcomes and motivation.

Regarding the first aspect, *DS-Hacker* adopts a constructivist approach, aiming to facilitate the connection between newly taught information and the learner's existing knowledge. To achieve this, the game uses analogies, which compare parts of structures between two domains [4]. These domains must share symmetrical relations among their components, with the goal of transferring ideas and concepts from a familiar domain (referred to as the source or base) to an unfamiliar one (known as the target) [5].

Concerning perceptual realism, it refers to "how closely objects, environments, and events depicted match those that actually exist" [8]. To evaluate the effects of perceptual realism, two versions of *DS-Hacker* with different levels of perceptual realism were developed. The first version is a 3D adventure PC game, while the second version is a 2D adventure PC game. Both games differ in their dimensionality, graphics, and physics. However, narrative elements, game challenges, levels, and learning aspects remain consistent across both versions of the game.

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This demo paper describes the learning aspects and core game concepts of *DS-Hacker* (2D and 3D). We discuss the learning theory and pedagogical approach employed for effective knowledge transmission. Additionally, we list the learning objectives and activities covered by the game. Furthermore, we explain the narrative aspects, aesthetics, and game mechanics used to convey the learning experience.

2 Related Work

Educational video games have become popular among computer science educational researchers. In a comprehensive systematic literature review, Petri and Gresse von Wangenheim [9] found 108 games and 117 evaluations related to the computer science field. However, as of 2020, only sixteen educational video games focusing on data structures were reported in the academic literature [11].

Concerning the games that focus on tree data structures, we highlight four. The first one, called *Elemental: The Recurrence*, is a 3D puzzle-coding game that intends to teach the recursive depth-first search (DFS) algorithm of a binary tree [3]. The second game focuses on Adelson-Velsky and Landis (AVL) trees, and it is an adaptation of the classic game *Mario* [14]. The third game, called *AVL Tree Game*, is a mobile casual-puzzle game, and it intends to teach the AVL tree rotation and the add algorithm [13]. More recently, Jiménez-Hernández et al. [6] reported *Tree Legends with UnityChan*, a game for learning tree traversal and search algorithm. The game focuses on binary, ternary, and quaternary trees.

3 Game Description

DS-Hacker is a PC video game with two versions that vary in their level of perceptual realism. One version of the game is a 3D third-person adventure (Fig. 1) developed with Unity. This version features representational 3D graphics and accurate physics, resulting in complex navigation mechanics that require the player to use the keyboard and mouse. The second version of *DS-Hacker* is a 2D top-down adventure game (Fig. 2) developed with RPG Maker MV. The 2D version has abstract graphics and simple physics, making the navigation mechanics straightforward, with the player moving over a flat surface. Its main controller is the mouse, and the keyboard is optional. Both versions of the game were designed to teach the BST data structure to students enrolled in introductory programming courses in higher education environments. It specifically targets bachelor students in engineering, computer science, or mathematics schools with programming courses. The game's content was selected based on the guidelines for undergraduate degree programs [1], ensuring it aligns with the curricula of many introductory programming or data structures courses.

Regarding the learning aspects, *DS-Hacker* (2D and 3D) was designed from a constructivist stance, which posits that learners build their knowledge by connecting new information with familiar experiences. The assumptions about how people learn were derived from Kolb's experiential learning theory and Kolb's experiential learning cycle [7]. Consequently, the game's learning experience emulates this cycle, linking new information (e.g., BST conceptual knowledge) with familiar knowledge (e.g., previous gaming experiences).

Fig. 1. Screenshot of *DS-Hacker 3D* – Level 1.

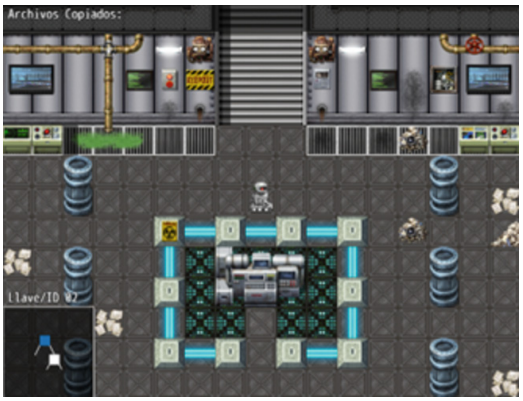

Fig. 2. Screenshot of *DS-Hacker 2D* – Level 1.

Regarding the learning content, *DS-Hacker* (2D and 3D) focuses on fundamental concepts of the BST. According to Sedgewick and Wayne [12], a BST is a specific order of a Binary Tree (BT). A BT is a structure made up of objects known as nodes, each of which contains two links that can be null or refer to other nodes. Additionally, each node can be pointed to by just one single node. On the other hand, BST nodes have two additional elements: the comparable key and the associated value. They satisfy the property that "the key in any node is larger than the keys in all nodes in that node's left subtree and smaller than the keys in all nodes in that node's right subtree" [12]. Consequently, the learning objectives (LOs) cover two topics: BT and BST. Table 1 presents the LOs.

Regarding the game genre, the rationale for adopting the adventure genre is its flexibility for teaching purposes. This story-driven genre incorporates conceptual puzzle elements that are ideal for teaching conceptual knowledge. For example, it allows for the introduction and explanation of concepts and theories through the game's narrative elements. Additionally, cognitive and conceptual puzzles can be used to create scenarios where players can practice the concepts taught in the story.

Concerning the game genre, the rationale for adopting the adventure genre is its flexibility for teaching purposes as well as its popularity. This story-driven genre presents conceptual puzzle elements that are ideal to teach conceptual knowledge. For example, it is possible to introduce and explain concepts and theory through the game story using narrative elements. Meanwhile, the cognitive and conceptual puzzles can be used to

create scenarios where the player can practice the concepts taught by the story. Finally, the adventure genre is a well-known genre among teenagers and young adults that presents a low learning curve.

The theme of *DS-Hacker* (2D and 3D) is cyberpunk science fiction, and its story follows the Hero's Journey structure [2], a narrative progression used in many myths and classic tales. The game's narrative takes place in a distant future, where a corrupt corporation disrupts society's balance. In the game, the player assumes the role of a robotic hacker, created by activists to infiltrate the computational systems of these corrupt corporations. The robot must traverse several mazes, called *Data Systems*, consisting of interconnected chambers, and extract information stored within each chamber of the computational systems. However, before embarking on the quest, the robot undergoes training and calibration by its creator, Anonymous, a non-player character who guides the player through the game levels. These events mark the beginning of the hero's transformation. The story is presented with appealing graphics, music, sound effects, and a futuristic game environment[1], creating an immersive atmosphere aligned with the game's narrative and designed to increase players' immersion and fantasy, thereby enhancing their intrinsic motivation.

Concerning the game world, *Data Systems* are places where corporations hide and protect their information. The structure of these systems follows the same organization as well-known data structures. Due to the game's learning objectives, the *Data Systems* reflect the structure of BTs and BSTs, and many key elements of the game environment represent important elements of these data structures. For example, a *Data System* that represents a BST consist of a set of rooms that represents the BST nodes. These rooms possess portals, an ID, and a central computer and are organized following the BST property. Portals represent the links that point to other nodes, and deactivated portals represent null values. The room ID represents the BST comparable key, and the information stored in the central computer represents the node's associated values.

Narrative elements play a primary role in teaching the conceptual knowledge of BST. The game's story progresses through monologues delivered by Anonymous, who appears at the beginning of each level or upon completing a challenge. These monologues introduce the missions of each level and the essential BT and BST concepts needed to overcome them. To enhance the understanding of BT and BST concepts, Anonymous employs analogies between the game environment described above and the BT and BST data structures. These analogies aim to facilitate the creation of new knowledge by relating it to the gaming knowledge.

Regarding the User Interface (UI), it is designed to reinforce the BT and BST concepts. For example, the map of the game world serves as a visual representation of a BST. The pause menu includes an option to display cards featuring the concepts taught in the level. This allows players to pause the game and review these concepts to tackle challenges effectively. By incorporating these UI elements, the game reduces the cognitive load on players by providing helpful reminders related to BT and BST concepts.

DS-Hacker (2D and 3D) game consists of four levels. Level one serves as a tutorial, introducing players to game controllers, UI, game world, and story. Challenges in this level focus on exploration, allowing novice players to become familiar with game

[1] https://www.dropbox.com/s/eoecefxjqx3pnr2/Gameplay%20DS-Hacker%203D.mkv?dl=0.

controls and navigation skills. Additionally, it allows the players to get familiar with the game world. Level two introduces the concept of BT and node structure. Level three

Table 1. Levels, topics, intended learning objectives (LOs), and learning activities (LAs) of *DS-Hacker* (2D and 3D).

Level	Topics	LOs	Learning Activities
Level 1	No topic	No LOs	No learning activities
Level 2	Binary Tree node	LO1. The student should understand the concept of BT LO2. The student should define the basic elements that compose a BT node	LA1. Read and listen the BT definition LA2. Read and listen the node definition and its basic components LA3. Read and listen the link definition (reference/pointers) LA4. Relate the portals (links) with the concept of reference/pointers LA5. Relate the chambers of the game environment with the BT node structure and components
Level 3	Binary Tree structure	LO3. The student should identify BTs LO4. The student should identify the BT's components	LA6. Read and listen the definition of the left and right child LA7. Read and listen the definition of the parent node LA8. Read and listen the definition of a sub-tree LA9. Identify the left and right child of the BT represented by the game environment LA10. Identify the root node of the BT represented by the game environment
Level 4	Binary Search Tree	LO5. The student should explain the BST property LO6. The student should identify the BSTs LO7. The student should solve problems using the BST property LO8. The student should determine whether the BST property is unfulfilled	LA11. Read and listen the definition of the basic components of a BST LA12. Read and listen the definition of the BST property LA13. Apply the BST property to search for specific nodes

revisits the BT structure and its component names. Level four introduces the BST data structure, its unique components, and properties. Table 1 summarizes the topics, LOs, and activities for each level.

4 Conclusion

This demo paper presented a detailed description of two prototypes of an educational video game for learning BST, called *DS-Hacker* (2D and 3D). Specifically, the paper provided a detailed description of the video game's learning aspects focusing on the learning theory, pedagogical approach, learning objectives and learning activities. Then, the paper described how the learning aspects were reflected in the game elements, such as the game narrative, challenges, and game world. It was expected that the rigorous match between the learning aspects and the game elements increases the video game's potential to convey learning of abstract non-intuitive conceptual knowledge. Moreover, the two versions of DS-Hacker were evaluated in 2020 [10]. Results were promising and showed the potential of the video game's approach.

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