

**FEDERAL UNIVERSITY OF FRONTEIRA SUL
CAMPUS CHAPECÓ
COMPUTER SCIENCE UNDERGRADUATE COURSE**

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**USING MINECRAFT AS A TOOL FOR TEACHING
GRAPH THEORY TO STUDENTS WITH ADHD**

**CHAPECÓ
2025**

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USING MINECRAFT AS A TOOL FOR TEACHING
GRAPH THEORY TO STUDENTS WITH ADHD / Ana Clara
Brusamarello Barbosa - 2025.

2 f.

Advisor: Prof. Dr. Andrei de Almeida Sampaio Braga

Final Undergraduate Proposal (Undergraduate) - Federal University of Fronteira Sul, Computer Science Undergraduate Course, Chapecó, SC, 2025.

1. Gamification 2. Education 3. ADHD 4.
Graph Theory 5. Minecraft I. Braga, Dr. Andrei de Almeida Sampaio, orient. II. Federal University of Fronteira Sul. III. Título.

ANA CLARA BRUSAMARELLO BARBOSA

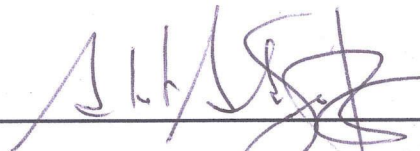
**USING MINECRAFT AS A TOOL FOR TEACHING GRAPH THEORY TO
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Final Undergraduate Proposal submitted to the Federal University of Fronteira Sul
in partial fulfillment of the requirements for the degree of Bachelor in Computer
Science.

Advisor: Prof. Dr. Andrei de Almeida Sampaio Braga

This Final Undergraduate Proposal was evaluated and approved by the examiners on: 12/12/2025.

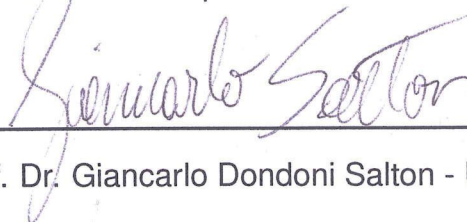
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Using Minecraft as a Tool for Teaching Graph Theory to Students with ADHD

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Abstract. Teaching highly abstract concepts in computer science remains a significant challenge, particularly when considering subjects such as graph theory, which demands strong logical reasoning and concept visualization skills. These difficulties are intensified for students diagnosed with Attention Deficit Hyperactivity Disorder (ADHD), who often struggle with traditional, linear and minimally interactive instructional approaches. This study aims to investigate the impact of an activity implemented in Minecraft on teaching and learning Kruskal's algorithm, focusing especially on students with ADHD. The activity was designed following the methodology proposed by Honda *et al.* [2022], which structures the development process into the stages of conception, ludification, and evaluation. Learning outcomes were assessed using an adapted version of the evaluation model created by Savi *et al.* [2010], covering dimensions such as motivation, user experience, and knowledge acquisition. The results show high levels of engagement and positive learning outcomes for both ADHD and neurotypical participants, with the ADHD group achieving especially strong results across all dimensions. These findings suggest that Minecraft's interactive and visually structured environment effectively supports the comprehension of abstract graph concepts, making it a promising and inclusive tool for teaching complex algorithms.

Keywords: Gamification, Education, ADHD, Graph Theory, Minecraft

1 Introduction

The teaching of abstract concepts remains a persistent challenge in educational environments, particularly within fields such as computer science, where many foundational topics demand high levels of abstraction and logical reasoning. Graph theory serves as a prime example of this difficulty, given that its abstract representations and conceptual rigor frequently hinder comprehension and challenges students' capacity to visualize and internalize its concepts [Bondy and Murty, 2008]. Beyond its inherent abstraction, learning graph-based reasoning and algorithmic thinking requires students to translate theoretical structures into concrete problem-solving processes. Despite these obstacles, graph theory is essential for the training of computing professionals due to its broad applicability in real-world scenarios, including network analysis, logistics, optimization, artificial intelligence, and routing problems. However, this challenge becomes even more pronounced when considering students diagnosed with Attention Deficit Hyperactivity Disorder (ADHD), who often experience additional barriers when engaging with highly abstract or theoretically dense content.

Research in education and psychology indicate that students with ADHD face difficulties that extend beyond individual cognitive limitations. As highlighted by Mahdi *et al.* [2017], traditional teaching methods often intensify difficulties with attention, organization, and task persistence, as they tend to be rigid, sequential, and offer limited interactivity. Similarly, DuPaul and Volpe [2009] note that these students frequently exhibit impaired academic performance, especially in activities requiring sustained attention and logical abstraction. This scenario is aggravated by the steady global rise in ADHD diagnoses. For instance, rates among children and adolescents in the United States increased from 6.1% to 10.2% between 1997 and 2016, revealing a growing educational demand that also resonates in other countries

[Xu *et al.*, 2018]. This context underscores the need for pedagogical strategies that are both inclusive and responsive to diverse cognitive profiles.

Technological tools, interactive methods, and game-based learning have emerged as promising approaches for addressing these challenges, as they provide more dynamic, visual, and engaging learning experiences. Game-based learning environments, including serious games and challenge-driven activities, have demonstrated the ability to support students who struggle with traditional instruction. These environments foster active participation, guiding exploration, and reducing cognitive overload, while also providing structured tasks with clear goals and immediate feedback that help learners externalize reasoning processes and engage with abstract computational concepts [Papastergiou, 2009; Rieber *et al.*, 1998; Nazry and Romano, 2017]. Among digital platforms, Minecraft has gained attention as a flexible educational tool capable of promoting exploration, experimentation, and hands-on construction in virtual environments, with successful applications across a variety of pedagogical contexts [Gallagher, 2014; Baek *et al.*, 2020]. However, its potential for teaching graph theory remains largely unexplored, especially for learners with ADHD.

In response to this gap, the present work proposes a pedagogical activity implemented within the Minecraft environment to introduce core graph theory concepts to students with ADHD. The activity aims to make abstract structures more concrete and interactive while fostering engagement, comprehension, and retention. Additionally, a preliminary evaluation with a small group of participants examines the pedagogical impact of this approach, providing initial insights into how game-based learning can support the acquisition of complex computational concepts by students with attentional challenges.

The remainder of this paper is organized as follows.

Section 2 reviews the related work relevant to this study. Section 3 presents the theoretical background, outlining the fundamental concepts that support the activity proposed. Section 4 describes the methodology adopted throughout the project. Section 5 details the development and implementation of the activity. Section 6 reports and analyzes the results obtained. Finally, Section 7 concludes the paper by summarizing the main contributions and indicating directions for future research.

2 Related Work

This chapter presents a review of studies relevant to this research, organized around three thematic areas: educational games for teaching graph theory, pedagogical uses of Minecraft, and games designed specifically for learners diagnosed with ADHD. Collectively, these works provide an overview of how game-based learning and immersive environments have been leveraged to support conceptual understanding, engagement, and inclusivity in educational contexts.

A number of studies have explored the use of educational games to teach graph theory. Cordero *et al.* [2022] present a medieval-themed board game in which students model a map as a directed and weighted graph to assist a character in finding efficient routes, applying shortest-path algorithms such as Dijkstra and Bellman–Ford. Santos and Ferreira [2021] propose *Formigas em Grafos*, available in both board and digital formats, where students represent routes within an anthill as a graph and guide ants through optimized paths, reinforcing foundational path-finding concepts. Pavani *et al.* [2023] introduce *Graph Defender*, a digital game focused on breadth-first and depth-first search, encouraging students to apply these algorithms to protect a graph in an interactive scenario. Across these examples, playful and contextualized activities are used to transform abstract topics into approachable learning experiences, consistently yielding improvements in student engagement and comprehension.

Other works investigate the use of Minecraft as a pedagogical platform, highlighting its potential as an immersive, flexible, and motivating tool for learning. Gama *et al.* [2024] employ Minecraft to teach digital circuits through nine virtual laboratories that allow students to manipulate components and observe real-time outcomes, showing promise in reducing intimidation and dropout rates in the Computer Science course. Oliveira [2023] presents the *Ilha de Frações*, a Minecraft-based environment designed to support understanding of mathematical fractions through exploration and interaction with in-game structures. Trindade *et al.* [2020] adopt a constructionist approach to teaching computational thinking to elementary students, asking them to collaboratively design a new version of their school within Minecraft. Their evaluation indicates substantial gains in motivation, collaboration, logic, sequencing, and modular reasoning. Together, these studies reinforce the view that Minecraft is a powerful platform for promoting engagement and facilitating meaningful learning across diverse subjects.

A third line of research focuses on the development of digital games tailored to learners with ADHD. Mon-

teiro and Adamatti [2021] describe a neurofeedback-based endless-runner game that adapts gameplay based on real-time measurements of users' concentration levels, supporting attention regulation through individualized feedback loops. Alves *et al.* [2023] introduce *Bilhar Geográfico*, a geography-learning game for children with ADHD designed using a user-centered methodology guided by the PACT framework, incorporating elements such as reward systems, positive feedback, and controlled visual stimuli to address the cognitive needs of this population. These studies highlight the importance of adapting game mechanics to the attentional patterns, motivational profiles, and sensory processing characteristics of individuals with ADHD, demonstrating the potential of games as supportive tools for both learning and cognitive development.

Compared to these works, the present project offers a distinctive contribution by integrating all three dimensions: it uses graph theory as the core subject matter, employs Minecraft as an immersive and highly engaging learning environment, and intentionally incorporates pedagogical strategies tailored to the needs of students diagnosed with ADHD. By combining algorithmic concepts with inclusive game-based learning within a widely familiar virtual world, this study proposes an approach that aims not only to enhance conceptual understanding but also to foster sustained engagement and a positive learning experience for ADHD learners.

3 Theoretical Background

This section presents the theoretical foundations underlying the activity, covering essential graph theory concepts, interactive educational methods and tools, and considerations related to ADHD. It reviews the relevant subjects that justify the choice of content and approaches used later on.

3.1 Graph Theory Concepts

Graph theory is a key area of discrete mathematics that models relationships through vertices and edges, enabling the representation of networks and the analysis of how elements connect [Bollobás, 1998]. A *graph* $G = (V, E)$ consists of a set of vertices V and a set of edges E , where each edge connects two vertices $\{u, v\}$. A *subgraph* $G' = (V', E')$ satisfies $V' \subseteq V$ and $E' \subseteq E$ [Szwarcfiter, 2014]. When edges have associated weights, the structure becomes a *weighted graph* (G, w) , where $w : E \rightarrow \mathbb{R}$ assigns a weight to each edge, allowing the representation of costs, distances, or time [Bondy and Murty, 2008; Weiss *et al.*, 2023].

A *path* is a sequence of vertices connected by edges, and a *cycle* is a path that begins and ends at the same vertex [Bondy and Murty, 2008]. A graph is considered *connected* if there is a path between any two vertices; otherwise, it is *disconnected*. A *connected component* is a subgraph in which all vertices are mutually reachable [Cormen *et al.*, 2009].

A graph is a *tree* when it is connected and acyclic [Szwarcfiter, 2014]. A tree with $|V|$ vertices has exactly $|V| - 1$ edges and contains a unique path between any pair of vertices. In a connected graph $G = (V, E)$, a *spanning tree* is a subgraph that contains all vertices and only the $|V| - 1$ edges needed to maintain connectivity without cycles [Szwarcfiter, 2014]. Different spanning trees may exist for the same graph.

A *minimum spanning tree* (MST) is a spanning tree that minimizes the total weight of its edges [Cormen *et al.*, 2009]. Given $w : E \rightarrow \mathbb{R}$, the objective is to find a set $T \subseteq E$ that is connected, acyclic, and minimizes $\sum_{e \in T} w(e)$. MSTs are widely used in systems that require cost-efficient connections, such as transportation, communication, and power networks.

There are different classical algorithms for solving the minimum weight spanning tree problem. Two well known are Kruskal's and Prim's algorithms. Both are efficient, but use different strategies for selecting edges. In this paper, only Kruskal's algorithm will be discussed.

Kruskal's algorithm works by sorting all the edges of the graph in ascending order of weight and selecting the lightest edges that do not form cycles with those already chosen. The process ends when the spanning tree has exactly $|V| - 1$ edges, ensuring a connected structure with the lowest possible total cost [Cormen *et al.*, 2009].

3.2 Interactive Methods and Tools in Education

Interactive methods and digital tools increasingly support contemporary education by enhancing engagement and promoting active learning through play, experimentation, and student autonomy. Serious games, gamification strategies, and platforms such as Minecraft exemplify how interactive technologies enrich learning environments and respond to diverse educational needs.

Serious games incorporate playful elements into educational contexts to foster engagement and meaningful learning [Rieber *et al.*, 1998]. They allow students to explore concepts in safe scenarios and benefit from emotional and motivational effects, as shown by navigation-based games that positively influence players' mood and cognitive assimilation [Nazry and Romano, 2017]. Their multisensory experiences, problem-solving activities, and real-time feedback further expand traditional instructional approaches [Pastergiou, 2009].

Gamification applies game elements to non-game learning environments to increase motivation and participation [Kapp, 2012]. Rather than replacing traditional teaching, it complements it by supporting learning-by-doing, enabling students to apply theoretical concepts and strengthen problem-solving abilities [Orlandi *et al.*, 2018]. Challenges, rewards, and immediate feedback help sustain interest and persistence, enriching the pedagogical experience without discarding conventional methods [Bahia and Carvalho, 2024].

Minecraft, a sandbox game based on constructing and exploring three-dimensional block environments [Mojang, 2021], has recognized educational potential. It promotes creativity, exploration, and problem-solving through collaborative and active learning [Gallagher, 2014]. The platform supports curricular integration and allows students to engage with diverse concepts interactively and autonomously, fostering critical thinking and creative knowledge application [Baek *et al.*, 2020].

3.3 Attention Deficit Hyperactivity Disorder

According to the *Diagnostic and Statistical Manual of Mental Disorders (DSM-5-TR)* [American Psychiatric Association, 2022], ADHD is defined as a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development. Symptoms must appear before the age of twelve, occur in at least two different contexts, and cause clinically significant impairment in academic, social, or occupational performance. ADHD is presented into three categories, namely predominantly inattentive, predominantly hyperactive/impulsive, and combined. This variability in symptom intensity and expression makes diagnosis challenging and requires tailored educational and therapeutic strategies.

Students with ADHD face academic difficulties that extend beyond inattentiveness, often resulting from challenges with behavioral self-regulation, sustained attention, and organizational skills, which may lead to lower performance in tasks that require continuous focus [DuPaul and Volpe, 2009]. In addition, Mahdi *et al.* [2017], using the framework of the International Classification of Functioning, Disability and Health (ICF), emphasize that individuals with ADHD also experience barriers in social interaction, motivation for learning, and adaptation to school environments. These difficulties can be intensified by rigid pedagogical methods and limited teacher awareness, indicating the importance of educational interventions that respect individual learning profiles and promote inclusive development.

Hyperfocus is an aspect commonly observed in individuals with ADHD. It is defined as a state of intense and prolonged concentration on a single activity, commonly observed in individuals with ADHD. As described by Hupfeld *et al.* [2019], this phenomenon occurs when attention becomes deeply absorbed in tasks that are personally engaging, often causing the individual to ignore other demands or stimuli. While hyperfocus may enhance performance in areas of interest, it can also create challenges in contexts that require divided attention. According to Marciano [2019], games such as Minecraft can facilitate this immersive state because their open-ended and interactive structure encourages creative exploration and problem-solving. As a result, Minecraft can function as an effective educational tool by combining engaging challenges with learner autonomy, positively channeling hyperfocus to support content assimilation.

4 Methodology

This study was guided by two main methodological approaches: the methodology proposed by Honda *et al.* [2022] and the evaluation questionnaire developed by Savi *et al.* [2010]. The combination of these methods allowed for a structured design of the educational activity and a systematic evaluation of its outcomes.

This methodology [Honda *et al.*, 2022] provides a framework for designing educational activities that integrate digital tools and game elements to enhance student engagement. It comprises three stages: conception, ludification, and evaluation. The *conception* stage defines the learning

problem, target audience, theme, and content; *ludification* focuses on the design of game elements and learning mechanics following an Educational Game Design Document (EGDD); and *evaluation* involves testing the prototype to identify improvements, with possible iteration across stages. More specifically in the evaluation stage, an appropriate evaluation method needs to be selected to assess how effectively the activity supports the intended learning goals, such as a questionnaire or another instrument. For this project, it involved applying the activity to participants and then evaluating their experience using the questionnaire developed by Savi *et al.* [2010], allowing us to analyze both the perceived usability and the effectiveness of the learning process. Following this structured process ensured the alignment between pedagogical intent and the engaging characteristics of the game-based learning environment.

As mentioned earlier, the questionnaire proposed by Savi *et al.* [2010] was used as an assessment instrument. The questionnaire was originally proposed to evaluate educational games based on multiple dimensions that capture cognitive, affective, and usability aspects of the learning experience. The framework includes dimensions such as motivation, user experience, knowledge, and social interaction. Each dimension is represented by a set of statements rated on a Likert [1932] scale, allowing participants to express their degree of agreement regarding different aspects of the game or activity. Although the questionnaire is a general-purpose instrument and was not developed specifically to individuals with ADHD, it was chosen because of its multidimensional aspects, which are particularly relevant for this target group.

In this study, the questionnaire was adapted to better fit the context and objectives of the proposed activity. Specifically, the social interaction dimension was removed, since the goal of the activity was not to promote collaboration or communication among participants but rather to foster individual engagement and understanding of the topic. Additionally, a selection of the most relevant questions from each remaining dimension was made in order to shorten the instrument. This decision aimed to avoid making the evaluation process overly long or tedious, thereby maintaining participant engagement and ensuring more reliable responses. The adapted version of the questionnaire was applied after the activity was completed, allowing for an effective assessment of motivational and learning-related aspects.

The original questionnaire, written in Brazilian Portuguese, contained 43 statements. Following the adaptations described above, the final version used in this study consisted of 22 statements. The selected statements translated into English are presented in Table 1.

The activity was applied with a group of eight undergraduate students from the Computer Science course at Federal University of Fronteira Sul (UFFS). The group included four participants who reported having ADHD and four without, with the latter serving as the control group. The group consisted of four participants who reported having ADHD and four without ADHD, who composed the control group. The non-ADHD participants were selected through convenience sampling, as no specific selection criteria were applied and participation was voluntary.

The activity was conducted in a university computer

laboratory, with all participants working simultaneously at individual workstations. The session lasted approximately 15 to 20 minutes, and the questionnaire was administered immediately after the completion of the activity.

5 Activity Design and Development

The activity was designed to teach Kruskal's algorithm in an interactive and visual way, using Minecraft as the main environment. Players interact with different elements of the game's surroundings to explore the concept of a minimum spanning tree (MST), using redstone dust to connect and lit redstone lamps along specific paths.

As mentioned previously in Section 4, the development process followed the principles of the methodology proposed by Honda *et al.* [2022], organized into three stages (conception, ludification, and evaluation). These stages guided the activity design with a clear focus on the target audience, ensuring an accessible and engaging learning experience for students with ADHD.

5.1 Conception

During the *conception* stage, the learning problem, target audience, theme, and content were defined. The learning problem identified is the difficulty students face when approaching graph theory, a subject that is highly abstract and often challenging in Computer Science courses. Graph theory is introduced as an abstract and formal field, centered on mathematical structures and rigorous proofs [Bondy and Murty, 2008]. Such characteristics contribute to making the subject challenging for beginners, particularly students who struggle with abstract reasoning. The activity is aimed specifically at computer science students diagnosed with ADHD, as these students tend to face additional difficulties with abstract concepts and traditional instructional formats [American Psychiatric Association, 2022]. This refinement of the target audience guided early design decisions, emphasizing the need for a more concrete, visual, and interactive approach to support comprehension.

Minecraft was selected as the environment for the activity because of its widespread popularity, its successful use in prior educational initiatives, and its ability to represent algorithmic logic through visual elements [Gallagher, 2014]. These considerations shaped the theme and content of the activity, aiming to help learners explore MSTs through hands-on interactions that mirror the step-by-step of Kruskal's algorithm.

5.2 Ludification

In the *ludification* stage, the in-game elements, storyline, level design and aesthetic aspects were determined. Since the target audience of this study are students diagnosed with ADHD, the design choices prioritized clarity, structured tasks, and visual support. These choices align with characteristics and learning needs commonly described in ADHD research, such as the importance of minimizing distracting factors, using clear goals, and providing organized activities to sustain engagement [DuPaul and Volpe, 2009; Mahdi *et al.*, 2017]. The activity aimed to guide students through the step-by-step logic of Kruskal's algorithm, including identifying the edges with the smallest weights, avoiding cycles,

and ensuring that all vertices of the graph were properly connected.

To support engagement and provide narrative cohesion, the activity was framed through a simple storyline integrated into the game environment. The activity takes place in a village that has lost its power after a zombie attack, leaving the inhabitants frightened and turning several villagers into zombie versions of themselves. Dr. Kruskal, the villager responsible for maintaining the village's electrical system, is occupied searching for a cure, so he writes a book explaining to the player that the lights can only be restored by activating all redstone lamps in the village. As students progress through the stages, additional books left by Dr. Kruskal provide hints inspired by the logic of Kruskal's algorithm, guiding them toward making optimal, cycle-free connections. Once all lamps are activated, the village's power is restored and the narrative concludes with Dr. Kruskal finding a cure, offering a clear sense of resolution and reinforcing the purpose of the tasks completed throughout the activity.

The level design emphasized short, goal-oriented steps and the use of consistent and immediate feedback. Such elements are compatible with what is known about attentional patterns in ADHD, including the potential benefits of maintaining a clear sequence of actions and offering quick reinforcement to support focus [Hupfeld *et al.*, 2019]. Each phase of the activity presents a single, delimited task, and feedback is communicated instantly through visual signals in the game environment. This approach resonates with findings in digital game-based learning, showing that games with clearly defined challenges and immediate outcomes can enhance motivation and comprehension [Papastergiou, 2009].

5.3 Evaluation

5.3.1 Prototyping

During the *evaluation* stage, the prototype was created using the Figma [2025] platform. The basic graph structures were modeled to represent the challenges that would later be implemented in Minecraft.

As shown in Figures 1 and 2, the initial design focused on ensuring that the visual layout of the graphs could be effectively applied to the constraints of the Minecraft environment, considering that the game only allows connections along vertical and horizontal axes, so diagonal edges could not be represented directly. Therefore, the prototype was adjusted to maintain structural coherence and playability under these conditions.

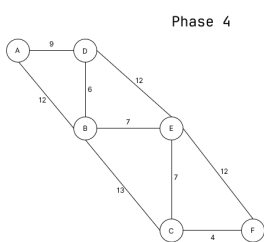


Figure 1. Original graph prototype created in Figma.

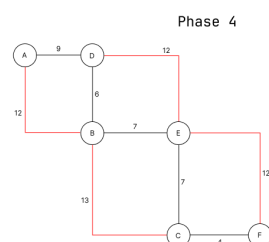


Figure 2. Graph adapted to Minecraft's constraints.



Figure 3. Top-down view of Phase 4 graph inside Minecraft.

5.3.2 Development

After finalizing the prototype, the structures were developed directly inside Minecraft. Each vertex of the graph was represented by a redstone lamp, while the edges were constructed using copper blocks to visually and mechanically represent the graph connections designed in the prototype (see Figure 3).

To simulate phase progression, each graph is placed inside a separate room, forming distinct levels of increasing complexity. As the player advances, both the graph size and the algorithmic steps involved in Kruskal's algorithm grow progressively more challenging. Hints related to the algorithm are left in books placed throughout the rooms, encouraging players to explore, read, and interact with the environment as part of the learning process.

Upon completing a phase, a button becomes available to open the iron door leading to the next room. Fireworks are triggered as a form of celebration and immediate visual feedback. In the corridor between phases, players are hit with *Bottles o' Enchanting* from a dispenser activated by a pressure plate, reinforcing the feedback received, as these items grant experience points upon impact, providing immediate visual and auditory feedback within the game. Once this process is complete, a hidden wall opens to reveal the entrance to the next phase, along with the amount of redstone dust needed to complete the next challenge given to the player's inventory.

Each room also includes a reset button, allowing players to restart the level in case they are unable to complete it correctly. When activated, this button removes all the redstone wire placed on the floor, clears the player's inventory, and provides the exact amount of redstone required to attempt the challenge again. Additionally, every time a player enters a new room, an automatic message is displayed in the chat to remind them to explore the environment. This message serves as a pedagogical prompt to encourage exploration and help players discover the clues about Kruskal's algorithm distributed throughout the game.

The main goal of the activity is for players to connect all redstone lamps using redstone dust along the copper block paths, simulating the construction of an MST. To maintain the integrity of the challenge, the game is set to Adventure Mode, preventing players from breaking the environment or placing redstone in incorrect locations. To achieve this, a specific parameter is assigned in the command that gives the redstone dust to the player, allowing it to be placed only on

copper blocks (see Figure 4).



Figure 4. Part of the code used to give players redstone dust inside Minecraft.

Phase control was implemented using Minecraft’s redstone circuits and command blocks. The in-game scoreboard system tracks the state of each graph vertex: when a redstone lamp has a parameter set as *lit=true*, its corresponding scoreboard variable (for example, “nodeA”) is set to 1, otherwise, it remains at 0. The next phase is unlocked only when all vertices in the current graph are simultaneously lit, following Kruskal’s algorithm logic that the MST must contain all vertices of the graph.

Overall, the system relied on a considerable amount of in-game logic. The entire structure used 173 “impulse” command blocks, 122 “repeat” command blocks, 1 “chain” command block, 116 redstone repeaters, and a very large number of redstone wires distributed across the levels. All of these mechanisms are hidden from players, embedded within the structure’s walls, roofs or underground, ensuring that only the functional and aesthetic parts of the environment are visible during the gameplay. This hidden system ensures the automation of game events, accurate phase progression, consistent feedback and control responses throughout the activity.

The complete Minecraft world created for the activity, along with a demonstration video showcasing the gameplay, is publicly available in a GitHub repository. This repository aims to support further exploration of the proposed activity by other researchers or educators interested in applying or adapting the approach. The materials can be accessed at <https://github.com/clairos/graph-theory-minecraft.git>.

6 Results and Discussion

This section presents and discusses the results obtained from the self-assessment questionnaire completed by the participants after finishing the activity.

Before analyzing the results in detail, it is relevant to describe the participants’ profile. The group consisted of eight male computer science students, four with an ADHD diagnosis and four who identified as neurotypical. Among the neurotypical participants, all had previously studied Kruskal’s algorithm, while in the ADHD group, two had prior knowledge of it and two had not. Six participants were between 18 and 24 years old, whereas the remaining two were between

25 and 29. Regarding race, seven participants identified as white and one as mixed (*parda*).

6.1 Data Analysis

To analyze the collected data, the responses were grouped into dimensions corresponding to the evaluated concepts, and the average score for each dimension was calculated. The questionnaire was answered using a Likert [1932] scale (translated into Brazilian Portuguese): 1 for “Strongly disagree”, 2 for “Disagree”, 3 for “Neutral”, 4 for “Agree”, and 5 for “Strongly agree”. The scores for negatively worded statements (e.g., “*There were moments when I thought about giving up.*”), where a lower result indicate a more positive outcome, were inverted using the formula $inverted\ score = 6 - original\ score$ so that higher values consistently reflected better outcomes. After this adjustment, the mean was calculated for each dimension: motivation, user experience, and knowledge.

6.1.1 ADHD Group

According to the results presented in Table 1, the group of students with ADHD presented consistently high results across all three dimensions. Regarding motivation, the average score was 4.78, indicating strong engagement, interest, and relevance of the activity. Participants demonstrated high willingness to learn and maintain focus during the task, suggesting that the interactive nature of the activity successfully supported sustained attention.

The user experience dimension also received great evaluations, with an average of 4.80. Students reported that the activity was immersive and enjoyable, while maintaining an appropriate challenge level. That also indicated that feedback and progress tracking helped them stay motivated and avoid distraction, reinforcing the suitability of game-based learning environments for learners with ADHD.

Finally, in the knowledge dimension, the average score was 4.58. Participants expressed confidence in understanding how Kruskal’s algorithm works and in applying it to graph problems.

In summary, the responses indicated that the visual and interactive aspects of the activity contributed to better comprehension and recall of the concepts.

6.1.2 Neurotypical Group

The neurotypical participants also rated the experience positively, although their averages were slightly lower overall (see Table 1). For motivation, the group obtained an average of 4.28, indicating good engagement but with more variability among responses. Some participants rated low on their interest in exploring more about the topic, which could possibly be due to prior familiarity with the algorithm or different learning preferences.

The user experience dimension showed an average score of 4.40, although a few participants mentioned brief moments of reduced immersion. The challenge level was generally seen as balanced, yet some participants noted mild difficulties or slightly less engagement compared to those in the ADHD group.

In the knowledge dimension, the average score was 3.75. While participants acknowledged learning benefits, they reported a slightly lower sense of mastery or retention

Table 1. Average responses by dimension and question for ADHD and Neurotypical participants.

Statement	ADHD Group	Neurotypical Group
Motivation	4.78	4.28
There was something interesting at the beginning of the activity that captured my attention.	4.75	4.50
The Minecraft environment design was attractive and engaging.	5.00	4.50
I enjoyed the activity enough to want to learn more about Kruskal's algorithm.	4.50	3.25
Studying Kruskal's algorithm is relevant to my interests or academic training.	5.00	3.75
The activity was harder to understand than I would have liked.	1.25 (4.75) ¹	1.25 (4.75) ¹
There was so much information that it was difficult to identify the key points of the algorithm.	1.50 (4.50) ¹	2.00 (4.00) ¹
I could not understand a considerable part of how the algorithm works.	1.25 (4.75) ¹	1.75 (4.25) ¹
Completing the exercises related to Kruskal's algorithm gave me a sense of accomplishment.	4.75	4.75
The feedback during the activity helped me feel that my effort was worthwhile.	5.00	4.75
User Experience	4.80	4.40
I lost track of time while performing the activity.	5.00	4.75
There were moments when I thought about giving up.	1.75 (4.25) ¹	1.25 (4.75) ¹
I felt motivated to learn from the activity.	5.00	3.75
I enjoyed the activity and did not feel anxious or bored.	5.00	5.00
The activity was appropriately challenging (neither too easy nor too hard).	4.25	3.50
I felt successful when applying Kruskal's algorithm.	4.75	4.25
I noticed progress in my learning of Kruskal's algorithm throughout the activity.	5.00	4.00
I enjoyed performing the activity for a long time.	5.00	4.25
I would like to repeat the experience at another time.	5.00	4.75
At times, I was hoping for the activity to end soon.	1.25 (4.75) ¹	1.00 (4.00) ¹
Knowledge	4.58	3.75
After the activity, I can recall more information about Kruskal's algorithm.	4.50	4.25
After the activity, I can better understand how Kruskal's algorithm works.	5.00	3.25
After the activity, I feel more capable of applying Kruskal's algorithm to solve graph problems.	4.25	3.75

¹ Average obtained using the *inverted score* formula.

compared to the ADHD group.

This analysis suggests that the game-based and visual aspects of the activity may have had a more significant impact on learners with attentional difficulties.

6.1.3 Comparative Analysis

When comparing the two groups, students with ADHD showed slightly higher averages in every category: motivation (4.78 vs. 4.28), user experience (4.80 vs. 4.40), and knowledge (4.58 vs. 3.75). Even though the differences are not particularly large, they are meaningful considering the target audience of the study.

Overall, the results indicate that the Minecraft environment effectively supported focus, engagement, and comprehension among students with ADHD. Elements such as immediate feedback, clear goals, and interactive problem-

solving seem to reduce cognitive overload and sustain motivation. In contrast, neurotypical students also benefited from the activity, but their responses suggest a more neutral engagement pattern, possibly because they are less affected by distractibility and therefore less influenced by the activity's supportive structure.

7 Conclusion

This study presented an educational activity designed to support the learning of Kruskal's algorithm through a game-based experience inside Minecraft, with focus on students diagnosed with ADHD. The proposal was motivated by the recurring difficulties students face when approaching abstract topics in graph theory and by the potential of immersive environments to provide structured, visually rich, and engag-

ing learning experiences. Guided by Honda *et al.* [2022]’s methodology and based on principles of game-based learning, the activity integrated concrete interactions, a narrative framework, and progressive challenges to help transform studying an abstract algorithm into a more accessible and meaningful experience.

Compared to existing works, the project stands out by combining three dimensions rarely explored simultaneously: graph theory as the central learning content, Minecraft as an interactive medium, and specific pedagogical considerations for learners with ADHD. While several studies use games to teach graph concepts, others explore Minecraft in education, and some focus on designing tools for ADHD students, this proposal integrates all three areas into a single structured activity. The development process involved identifying the target audience, defining the theme, creating prototypes, adapting graph structures to the constraints of the game, implementing multiple levels with increasing complexity, and embedding feedback mechanisms, clear goals, and environmental cues aligned with the cognitive and attentional needs of the target group.

The results obtained through the adapted Savi *et al.* [2010] questionnaire indicate strong levels of motivation, positive user experience, and meaningful learning outcomes. Students with ADHD demonstrated particularly high engagement, reporting sustained attention, clear understanding of the algorithm, and a positive experience throughout the activity. Neurotypical students also evaluated the activity favorably, although with slightly lower averages in knowledge and motivation, suggesting that the design may especially benefit learners who struggle with abstract or less structured instructional formats. Altogether, the findings reinforce the potential of integrating game mechanics, visual representations, and narrative elements to enhance comprehension and engagement, highlighting Minecraft as a promising tool for inclusive and effective teaching of complex computer science topics.

In future extensions of this work, several promising directions could be explored. One possibility is the development of a multiplayer version of the activity, allowing students to collaborate or compete while applying Kruskal’s algorithm, potentially enhancing engagement and fostering cooperative learning dynamics. Another avenue involves expanding the scope of the challenges by introducing larger and more complex graphs, enabling the algorithm to be applied in scenarios that demand more strategy, coordination, and cognitive effort. These potential extensions highlight opportunities for expanding the project and broadening its educational impact in future work.

References

Alves, S. V. L., Lima, C. P., and Alves, E. C. M. (2023). Desenvolvimento de um Jogo Digital Educativo para o Aprendizado de Geografia para Crianças com TDAH – Biliar Geográfico. In *Anais do VIII Congresso sobre Tecnologias na Educação (Ctrl+e)*, pages 396–403, Porto Alegre, RS, Brasil. SBC. DOI: 10.5753/ctrl.2023.232961.

- American Psychiatric Association (2022). *Diagnostic and Statistical Manual of Mental Disorders: DSM-5-TR*. American Psychiatric Publishing, Washington, DC, 5 edition.
- Baek, Y., Min, E., and Yun, S. (2020). Mining Educational Implications of Minecraft. *Computers in the Schools*, 37(1):1–16. DOI: 10.1080/07380569.2020.1719802.
- Bahia, A. D. A. and Carvalho, A. F. R. (2024). O uso da gamificação como ferramenta de ensino-aprendizagem. Trabalho de Conclusão de Curso (Graduação) – Universidade Estadual do Maranhão.
- Bollobás, B. (1998). *Modern Graph Theory*. Springer Science & Business Media, New York.
- Bondy, J. A. and Murty, U. S. R. (2008). *Graph Theory*, volume 244 of *Graduate Texts in Mathematics*. Springer, New York.
- Cordero, A., Jordan, C., Murillo-Arcila, M., and Sanabria-Codesal, E. (2022). A game for learning how to model in graph theory. *Mathematics*, 10(12):1969. DOI: 10.3390/math10121969.
- Cormen, T. H., Leiserson, C. E., Rivest, R. L., and Stein, C. (2009). *Introduction to Algorithms*. MIT Press, Cambridge, 3 edition.
- DuPaul, G. J. and Volpe, R. J. (2009). ADHD and learning disabilities: Research findings and clinical implications. *Current Attention Disorders Reports*, 1(4):152–155. DOI: 10.1007/s12618-009-0021-4.
- Figma, I. (2025). Figma: Collaborative interface design tool. <https://www.figma.com/> (accessed 2025-11-07).
- Gallagher, C. (2014). *Minecraft in the Classroom: Ideas, Inspiration, and Student Projects for Teachers*. Peachpit Press.
- Gama, G. V. d. M., Fernandes, G. A., Campano Junior, M. M., and Aylon, L. B. R. (2024). Jogando, aprendendo e construindo: utilizando o Minecraft como ferramenta de auxílio no ensino de circuitos digitais. In *Anais do XXIII Simpósio Brasileiro de Jogos e Entretenimento Digital (SBGAMES)*, pages 1223–1232, Porto Alegre. SBC. DOI: 10.5753/sbgames.2024.240935.
- Honda, F., Pires, F., Pessoa, M., and Melo, R. (2022). Aplicando learning design na ludificação de percurso em grafos: uma jornada de aprendizagem. In *Anais do XXXIII Simpósio Brasileiro de Informática na Educação (SBIE)*. DOI: 10.5753/22444.
- Hupfeld, K. E., Abagis, T. R., and Shah, P. (2019). Living “in the zone”: hyperfocus in adult ADHD. *ADHD Attention Deficit and Hyperactivity Disorders*, 11(2):191–208. DOI: 10.1007/s12402-018-0272-y.
- Kapp, K. M. (2012). *The Gamification of Learning and Instruction: Game-Based Methods and Strategies for Training and Education*. Pfeiffer, San Francisco.
- Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 140(22):5–55.
- Mahdi, S., Viljoen, M., Massuti, R., Selb, M., Almodayfer, O., Karande, S., de Vries, P. J., Rohde, L., and Bólte, S. (2017). An international qualitative study of ability and disability in ADHD using the WHO-ICF framework. *European Child & Adolescent Psychiatry*, 26(10):1219–1231. DOI: 10.1007/s00787-017-0983-1.

- Marciano, A. C. B. (2019). Uma abordagem sobre a aplicação de jogos digitais como tecnologia assistiva para crianças com TDAH no processo da aprendizagem. Trabalho de Conclusão de Curso (Graduação) – Universidade Federal do Rio Grande do Sul.
- Mojang (2021). Minecraft. <https://www.minecraft.net/> (accessed 2025-04-25).
- Monteiro, G. T. and Adamatti, D. F. (2021). Desenvolvimento de um Jogo Sérioo controlado por Neurofeedback para auxílio no tratamento de pessoas com TDAH. In *Anais do XX Simpósio Brasileiro de Jogos e Entretenimento Digital (SBGAMES)*, pages 867–876, Porto Alegre. SBC.
- Nazry, M. N. N. and Romano, D. M. (2017). Mood and learning in navigation-based serious games. *Computers in Human Behavior*. DOI: 10.1016/j.chb.2017.03.040.
- Oliveira, J. N. F. d. (2023). Gamificação na matemática: proposta de modelagem no ensino de fração com Minecraft. Trabalho de Conclusão de Curso (Graduação) – Universidade Estadual da Paraíba.
- Orlandi, T. R. C. *et al.* (2018). Gamificação: uma nova abordagem multimodal para a educação. *Biblios Journal of Librarianship and Information Science*, (70):17–30. DOI: 10.5195/biblios.2018.447.
- Papastergiou, M. (2009). Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education*, 52(1). DOI: 10.1016/j.compedu.2008.06.004.
- Pavani, R. B., Campano Junior, M. M., and Aylon, L. B. R. (2023). Busca em largura e profundidade aplicado a jogos educativos: estudo de caso no projeto do jogo Graph Defender. In *Anais do XXII Simpósio Brasileiro de Jogos e Entretenimento Digital (SBGAMES)*. SBC.
- Rieber, L. P., Smith, L., and Noah, D. (1998). The value of serious play. *Educational Technology*, 38(6):29–37.
- Santos, A. V. and Ferreira, A. B. (2021). Formigas em grafo: uma proposta de jogos digital e de tabuleiro para o ensino de algoritmos em grafos. *Revista de Sistemas e Computação*, 11(3). DOI: 10.36558/rsc.v11i3.7477.
- Savi, R., Von Wangenheim, C. G., Ulbricht, V., and Vanzin, T. (2010). Proposta de um modelo de avaliação de jogos educacionais. *RENTE – Revista Novas Tecnologias na Educação*, 8(3). DOI: 10.22456/1679-1916.18043.
- Szwarcfiter, J. L. (2014). *Teoria Computacional de Grafos*. Elsevier, Rio de Janeiro.
- Trindade, G. M., Fernandes, F. P., Barbosa, L. S. d. O., and Souza, D. R. d. (2020). O uso do Jogo Digital Minecraft para Estimular o Pensamento Computacional e a Aprendizagem Colaborativa no Ensino Fundamental I: Um Relato de Experiência. In *Anais do XXXI Workshop de Informática na Escola (WIE)*. SBC. DOI: 10.5753/cbie.wie.2020.219.
- Weiss, E., Felner, A., and Kaminka, G. A. (2023). A generalization of the shortest path problem to graphs with multiple edge-cost estimates. In *Proceedings of the 26th European Conference on Artificial Intelligence (ECAI 2023)*, pages 2607–2614. IOS Press. DOI: 10.3233/FAIA230567.
- Xu, G., Strathearn, L., Liu, B., Yang, B., and Bao, W. (2018). Twenty-Year Trends in Diagnosed Attention-Deficit/Hyperactivity Disorder Among US Children and Adolescents, 1997–2016. *JAMA Network Open*, 1(4):e181471. DOI: 10.1001/jamanetworkopen.2018.1471.