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

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Abstract. Introduction: *Teaching abstract concepts in computer science remains challenging, particularly in graph theory, which requires strong logical reasoning and concept visualization. These difficulties are intensified for students with Attention Deficit/Hyperactivity Disorder (ADHD), who struggle with traditional, linear, and minimally interactive instructions.* ***Objective:*** *This study investigates the impact of a Minecraft-based activity on teaching Kruskal's algorithm, focusing especially on students with ADHD.* ***Methodology:*** *The activity's design followed the pedagogical methodology for serious games proposed by Honda et al. [2022]. Learning outcomes were assessed using an adapted version of the evaluation model by Savi et al. [2010], covering motivation, user experience, and knowledge acquisition.* ***Results:*** *Results indicate high engagement and positive learning outcomes for both ADHD and neurotypical participants, with the ADHD group achieving particularly strong results. These findings suggest that Minecraft's interactive and visually structured environment supports understanding of abstract graph concepts, making it a promising and inclusive tool for teaching complex algorithms.*
Keywords *Gamification, Education, ADHD, Graph Theory, Minecraft.*

1. Introduction

Teaching abstract concepts remains a challenge in education, particularly in fields such as computer science, where many topics require high levels of abstraction and reasoning. Graph theory exemplifies this difficulty, as its abstract representations often hinder students' ability to visualize and internalize concepts [Bondy and Murty 2008]. In addition, learning graph-based reasoning requires translating theoretical structures into practical problem-solving. Despite these challenges, graph theory is fundamental for computing professionals due to its wide range of applications, including network analysis, logistics, optimization, artificial intelligence, and routing [ACM and IEEE Computer Society 2020]. These challenges are even greater for students with Attention Deficit/Hyperactivity Disorder (ADHD), who may face additional barriers when dealing with highly abstract content.

Educational and psychological research indicates that students with ADHD struggle with attention, organization, and task persistence, difficulties that can be intensified by traditional teaching methods, which are typically rigid and offer limited interactivity [Mahdi et al. 2017]. As noted by DuPaul and Volpe [2009], these factors can lead to reduced academic performance, particularly in activities requiring sustained attention and logical abstraction. The growing global prevalence of ADHD highlights this issue, with diagnoses among children and adolescents in the United States increasing from 6.1% to 10.2% between 1997 and 2016 [Xu et al. 2018]. This trend reinforces the need for inclusive pedagogical strategies that address diverse cognitive profiles.

In this context, technological tools and game-based learning have emerged as promising approaches, offering dynamic, visual, and interactive experiences that support students who struggle with traditional instruction. Such environments encourage active participation, guided exploration, and immediate feedback, helping learners engage with abstract computational concepts while reducing cognitive overload [Papastergiou 2009; Rieber et al. 1998; Nazry and Romano 2017]. Among these tools, Minecraft stands out as a flexible platform that promotes exploration and hands-on construction in virtual environments and has shown successful applications in several educational contexts [Gallagher 2014; Baek et al. 2020]. However, its potential for teaching graph theory, particularly for learners with ADHD, remains largely unexplored.

In response to this gap, the present work proposes a pedagogical activity implemented in Minecraft to introduce core graph theory concepts to students with ADHD. The activity aims to make abstract structures (such as minimum spanning trees) more concrete and interactive while fostering engagement, comprehension, and retention. A preliminary evaluation with a small group of participants shows positive results in motivation, user experience, and perceived knowledge acquisition, particularly among students with ADHD, suggesting that the game-based environment can support learning of complex computational concepts for learners 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 proposed activity. 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 section reviews studies related to this research, organized into three areas: educational games for teaching graph theory, pedagogical uses of Minecraft, and games for learners with ADHD. Together, these works show that game-based and immersive approaches support conceptual understanding, engagement, and inclusivity in education.

Several studies explore educational games for teaching graph theory. Cordero et al. [2022] propose a medieval-themed board game where students model maps as directed and weighted graphs to find efficient routes using shortest-path algorithms such as Dijkstra and Bellman-Ford. Similarly, Santos and Ferreira [2021] present *Formigas em Grafos*, available in board and digital formats, where students represent routes in an anthill as a graph and guide ants through optimized paths. Pavani et al. [2023] introduce *Graph Defender*, a digital game focused on breadth-first and depth-first search. Santos et al. [2025] develop a mobile digital game, called *Missão Aspirapó*, that combines the concepts of planar graphs and Hamiltonian cycles. Overall, these works show that contextualized activities make abstract graph concepts more accessible.

Other studies investigate Minecraft as a pedagogical platform. Gama et al.

[2024] use Minecraft to teach digital circuits through virtual laboratories where students manipulate components and observe results in real time. Oliveira [2023] present *Ilha de Frações*, a Minecraft-based environment designed to support learning of fractions through exploration and interaction. Trindade et al. [2020] adopt a constructionist approach where students collaboratively recreate their school in Minecraft, improving motivation, collaboration, and computational thinking. Together, these studies highlight Minecraft's potential as an immersive and motivating learning environment.

A third line of research focuses on games designed for learners with ADHD. Monteiro and Adamatti [2021] describe a neurofeedback-based endless runner that adapts gameplay using real-time measurements of users' attention. Alves et al. [2023] introduce *Bilhar Geográfico*, a geography-learning game developed with a user-centered methodology guided by the PACT framework [Benyon 2011], incorporating rewards, feedback, and controlled visual stimuli. These studies emphasize adapting game mechanics to the attentional and cognitive characteristics of ADHD learners.

Compared to these works, the present study contributes by integrating all three dimensions: graph theory as the core subject, Minecraft as an immersive and engaging learning environment, and pedagogical strategies tailored to students with ADHD. By combining algorithmic concepts with inclusive game-based learning in a familiar virtual world, this approach aims to enhance conceptual understanding while fostering sustained engagement and a positive learning experience for ADHD learners.

3. Theoretical Background

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

3.1. Graph Theory Concepts

Graph theory is an area of discrete mathematics that formally represents relationships between elements [Bollobás 1998]. A *graph* consists of n vertices and m edges. In many applications, graphs are weighted, allowing edges to model quantities such as distance or time [Bondy and Murty 2008]. A graph is *connected* if there is a path between every pair of vertices. A connected and acyclic graph is called a *tree*, which contains exactly $n - 1$ edges and a unique path between any two vertices [Szwarcfiter 2018]. A *spanning tree* of a graph can be obtained by selecting a subset of its edges that preserves connectivity among all vertices and avoids cycles. In weighted graphs, a *minimum spanning tree* (MST) is a spanning tree whose total edge weight is minimal among all possible spanning trees [Cormen et al. 2022]. MSTs play a key role in applications that require cost-efficient network structures, such as communication, transportation, and infrastructure systems.

There are classical algorithms for finding an MST, among which Kruskal's and Prim's algorithms are well known. Both are efficient but use different strategies for selecting edges. In this paper, we deal with Kruskal's algorithm, which sorts all edges in ascending order of weight and iteratively selects the lightest edge that does not form cycles. The process ends when exactly $n - 1$ edges have been chosen, resulting in a connected structure with the lowest possible total cost [Cormen et al. 2022].

3.2. Interactive Methods and Tools in Education

Interactive methods and digital tools increasingly support contemporary education by promoting engagement and active learning through play and student autonomy. In this context, *serious games* integrate playful elements into educational environments to foster meaningful learning [Rieber et al. 1998], enabling students to explore concepts in safe scenarios while benefiting from emotional, motivational, and cognitive effects [Nazry and Romano 2017]. Their multi-sensory experiences, problem-solving activities, and real-time feedback expand traditional instructional approaches [Papastergiou 2009]. Similarly, *gamification* applies game elements to non-game learning contexts to increase motivation and participation [Kapp 2012], complementing traditional teaching through learning-by-doing and the application of theoretical concepts [Orlandi et al. 2018]. Challenges, rewards, and immediate feedback help sustain interest and enrich the pedagogical experience without replacing conventional methods [Bahia and Carvalho 2024].

Within this context of interactive methods, Minecraft, a sandbox game based on the construction and exploration of three-dimensional block environments [Mojang 2021], stands out for its educational potential. By promoting creativity, exploration, and problem-solving through collaborative and active learning [Gallagher 2014], the platform supports curricular integration and enables students to engage autonomously with diverse concepts, 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 characterized by persistent patterns of inattention and/or hyperactivity-impulsivity that interfere with functioning or development, with symptoms varying in intensity and expression. In academic contexts, students have difficulties related to behavioral self-regulation, sustained attention, and organizational skills, often resulting in lower performance in tasks that require continuous focus [DuPaul and Volpe 2009]. Additionally, individuals with ADHD may face barriers in social interaction, learning motivation, and adaptation to school environments [Mahdi et al. 2017]. 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 a phenomenon commonly observed in individuals with ADHD, characterized by intense and prolonged concentration on personally engaging activities, often to the exclusion of other stimuli [Hupfeld et al. 2019]. While this state may enhance performance in areas of interest, it can also pose challenges in situations that require divided attention. Games such as Minecraft can facilitate hyperfocus by promoting creative exploration and problem-solving, allowing this attentional state to be positively channeled to support learning and content assimilation [Marciano 2019].

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.

The methodology by Honda et al. [2022] provides a framework for designing educational activities that integrate digital tools and game elements to enhance engagement. It comprises three stages: *conception*, which defines the learning problem, target audience, theme, and content; *ludification*, which designs game elements and learning mechanics following an Educational Game Design Document (EGDD); and *evaluation*, which tests the prototype and may involve iteration across stages. In this work, the evaluation consisted of applying the activity to participants and assessing their experience through the questionnaire developed by Savi et al. [2010], enabling analysis of perceived usability and learning effectiveness. This structured process ensured alignment between pedagogical objectives and the game-based learning environment.

The questionnaire developed by Savi et al. [2010] was proposed to evaluate educational games based on 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 for individuals with ADHD, it was employed in this work 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. The social interaction dimension was removed, since the goal was not to promote collaboration among participants but to foster individual engagement and learning. Additionally, the most relevant questions from each remaining dimension were selected to shorten the instrument and avoid a long or tedious evaluation process, ensuring more reliable responses.

The original questionnaire, written in Brazilian Portuguese, contained 43 statements and was reduced to 22 after the adaptations described above; the selected statements, translated into English, are presented in Table 1 (see Section 6). The activity was conducted in a computer laboratory, outside classroom context, with eight undergraduate Computer Science students from the Federal University of Fronteira Sul (UFFS), selected through convenience sampling, four of whom reported having ADHD and four without ADHD, the latter serving as the control group. All participants worked simultaneously at individual workstations, without instructor intervention, during a 15–20 minute session, and the questionnaire was administered immediately afterward. It should be noted that this study was acknowledged by UFFS's Ethics Committee and no formal procedure was required since no personally identifiable or sensitive data was collected.

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 in Section 4, the development process followed the methodology proposed by Honda et al. [2022], organized into three stages (conception, ludification, and evaluation). These stages guided the activity design with a 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 identified problem was the difficulty students face when learning graph theory, a subject that can be particularly challenging for beginners and those who struggle with abstract reasoning [Bondy and Murty 2008]. The activity is aimed specifically at computer science students diagnosed with ADHD, who may experience additional difficulties with traditional instructional formats [American Psychiatric Association 2022]. This definition of the target audience guided the design toward a more concrete, visual, and interactive approach to support comprehension. Minecraft was selected as the environment for the activity due to its popularity, prior educational use, and ability to represent algorithmic logic through visual elements [Gallagher 2014].

5.2. Ludification

In the *ludification* stage, the in-game elements, storyline and level design were defined. Since the target audience of this study are students diagnosed with ADHD, the design prioritized clarity, structured tasks, and visual support, which aligned with characteristics described in ADHD research [DuPaul and Volpe 2009; Mahdi et al. 2017]. The activity guides 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 are connected.

To enhance engagement and narrative cohesion, the activity was framed within a storyline set in a village that lost its power after a zombie attack, which frightened the villagers and turned some into zombies. Dr. Kruskal, responsible for the village's electrical system and currently searching for a cure, leaves books explaining that the lights can only be restored by activating all redstone lamps. As students progress, additional books provide hints inspired by Kruskal's algorithm, guiding them to create optimal, cycle-free connections. Once all lamps are activated, the power is restored and Dr. Kruskal finds a cure, concluding the narrative and reinforcing the purpose of the tasks.

The level design prioritizes short, goal-oriented steps and consistent, immediate feedback, aligning with research on attentional patterns in ADHD and the benefits of clear action sequences to support focus [Hupfeld et al. 2019]. Each phase presents a single, well-defined task with instant visual feedback, an approach consistent with findings in digital game-based learning that highlight how clearly structured challenges and immediate outcomes can enhance motivation and comprehension [Papastergiou 2009].

5.3. Evaluation

During the *evaluation* stage, the prototype was created using the Figma platform [Figma 2026], where basic graph structures were modeled to represent the challenges later implemented in Minecraft. As shown in Figure 1, the design aimed to ensure that the graph layout would work within the constraints of the Minecraft environment, which only allows vertical and horizontal connections, preventing diagonal edges. Therefore, the prototype was adjusted to preserve structural coherence and playability.

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

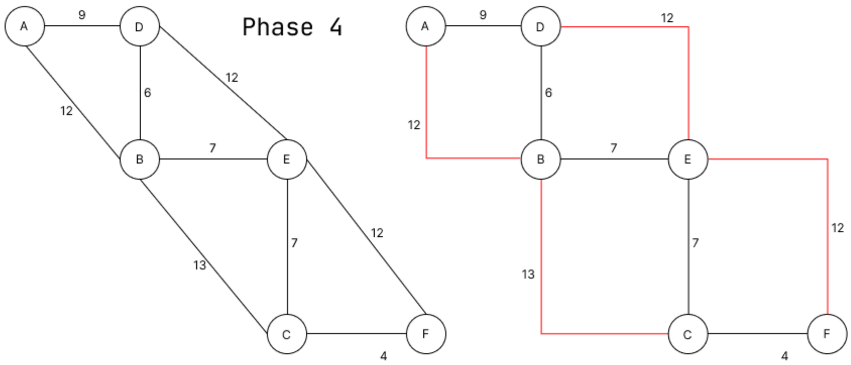

Figure 1. Original graph prototype created in Figma (left) and adapted graph following Minecraft's constraints (right).

Figure 2. Top-down view of Phase 4 graph inside Minecraft.

Figure 3. Snippet of the *can_place_on* parameter.

were constructed using copper blocks to visually and mechanically represent the graph connections designed in the prototype (see Figure 2).

To achieve phase progression, each graph is placed inside a separate room, forming levels of increasing complexity. As the player advances, the graph size and the algorithmic steps involved in Kruskal's algorithm grow progressively more challenging. Books with hints related to the algorithm are placed in each room, encouraging players to explore 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, as these items grant experience points upon impact. Afterward, a hidden wall opens to reveal the entrance to the next phase and the player receives the redstone dust required for the next challenge.

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 restores the required amount of redstone. 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 to connect all redstone lamps using redstone dust along the copper block paths, simulating the construction of an MST. To maintain the challenge's integrity, the game is set to Adventure Mode to prevent players from breaking the environment or placing redstone in incorrect locations. To this end, a specific parameter is set to allow redstone dust to be placed only on copper blocks (see Figure 3). 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 the requirement that the MST must contain all vertices of the graph.

Overall, the system relied on a considerable amount of in-game logic within Minecraft. The structure included 173 "impulse" command blocks, 122 "repeat" command blocks, 1 "chain" command block, 116 redstone repeaters, and numerous redstone wires distributed across the levels. These mechanisms are hidden inside walls, roofs, or underground so that only the functional and aesthetic elements are visible during gameplay, ensuring automated events, accurate phase progression, consistent feedback, and control responses. The world file and a gameplay demonstration video are publicly available in a GitHub repository [Brusamarello B. 2025].

6. Results and Discussion

Before analyzing the results, it is important to describe the participants' profile. The group consisted of eight male computer science students, four diagnosed with ADHD and four neurotypical. Among the neurotypical participants, all had previously studied Kruskal's algorithm, while in the ADHD group two had prior knowledge and two had not. Six participants were between 18 and 24 years old, and two were between 25 and 29. Regarding race, seven identified as white and one as mixed (*pardo*).

The response scores for the administered questionnaire are presented in Table 1. Responses were given using a Likert [1932] scale (translated into Brazilian Portuguese): 1 = "Strongly disagree", 2 = "Disagree", 3 = "Neutral", 4 = "Agree", and 5 = "Strongly agree". Scores of negatively worded statements were inverted via the formula $inverted\ score = 6 - original\ score$ so that higher values consistently represented better outcomes. After this adjustment, the average score for each statement and dimension was calculated.

6.1. ADHD Group

Students with ADHD showed high results across all dimensions. Motivation averaged 4.78, indicating engagement, interest, and sustained focus. User experience averaged 4.80, with participants regarding the activity as immersive, enjoyable, and appropriately challenging. This result also suggests that feedback and progress tracking helped maintain motivation and reduce distraction, reinforcing suitability for learners with ADHD. The knowledge dimension averaged 4.58, with participants reporting confidence in understanding and applying Kruskal's algorithm. Overall, responses imply that visual and interactive aspects supported comprehension and recall of the concepts.

6.2. Neurotypical Group

Neurotypical participants also evaluated the experience positively, although with slightly lower averages. Motivation averaged 4.28, indicating good engagement but greater variability in responses, with some participants reporting less interest in further

Table 1. Average response scores by statement and dimension 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
At times, I considered abandoning the effort.	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 (5.00)[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 score obtained using the *inverted score* formula.

exploration, possibly due to familiarity with the algorithm or learning preferences. User experience averaged 4.40, with occasional reports of reduced immersion. The challenge level was generally considered balanced, with only mild difficulties or slightly lower engagement than the ADHD group. In the knowledge dimension, the average score was 3.75; although participants acknowledged learning benefits, they reported a lower sense of mastery compared to the ADHD group. These results suggest that the game-based and visual aspects may have a stronger impact on learners with attentional difficulties.

6.3. Comparative Analysis

Comparing the groups, students with ADHD presented slightly higher averages in all dimensions: motivation (4.78 vs. 4.28), user experience (4.80 vs. 4.40), and knowledge (4.58 vs. 3.75). Although a formal statistical evaluation was rendered impractical due to the small sample size, these consistent gains suggest a meaningful trend considering the target audience of the study.

Overall, these preliminary findings indicate that the Minecraft environment supported focus, engagement, and perceived comprehension among students with ADHD. Elements such as immediate feedback, clear goals, and interactive problem-solving appear to mitigate cognitive overload and sustain motivation. Neurotypical students also benefited from the activity, but their responses tended toward a more neutral engagement pattern, possibly because they are less affected by distractibility and therefore less influenced by the activity's structure.

7. Conclusion

This study presents an educational activity in Minecraft designed to support learning of Kruskal's algorithm, focusing on students with ADHD. Motivated by the challenges of teaching abstract graph theory concepts, the activity followed the methodology of Honda et al. [2022] and principles of game-based learning, combining concrete interactions, narrative elements, and progressive challenges to make the algorithm more accessible.

Compared to existing works, this study integrates graph theory as the core learning content, Minecraft as an interactive medium, and pedagogical considerations for learners with ADHD into a structured activity. The development process defined the theme and target audience, created prototypes, adapted graph structures to the game environment, and implemented progressively complex levels with feedback and cues aligned with attentional needs. Preliminary results from the adapted Savi et al. [2010] questionnaire suggest high motivation, positive user experience, and meaningful perceived learning, with strong engagement among students with ADHD. Neurotypical students reported slightly lower knowledge and motivation scores, offering a preliminary indication that the activity particularly benefits learners who struggle with abstract instruction.

In future extensions of this work, several promising directions could be explored. One possibility is to develop a multiplayer version of the activity, allowing students to collaborate or compete, potentially enhancing engagement and fostering cooperative learning dynamics. Another avenue involves expanding the scope of the challenges by introducing more complex graphs, enabling the algorithm to be applied in scenarios that demand more strategy, coordination, and cognitive effort. A third direction is to integrate the activity into regular classes, making it possible to assess its impact within this context and the influence of instructor guidance.

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