Missão Aspirapó: A digital game for teaching and learning graphs

Matheus V. Santos[1], **Andrei de A. S. Braga**[1], **Felipe Grando**[1], **Raquel A. Pegoraro**[1]

[1] Universidade Federal da Fronteira Sul (UFFS)
SC-484, Km 02 - Fronteira Sul, Chapecó – SC, 89815-899

matheus.eu.mv@gmail.com
{andrei.braga,felipegrando,raquel.pegoraro}@uffs.edu.br

Abstract. Introduction*: Currently, the integration of information and communication technologies into daily life directly influences teaching models at different educational levels. Additionally, there are well-known educational challenges in the field of computing, resulting in high rates of failure and dropout. Among these challenges, students' difficulties with the subfield of graphs stand out.* ***Objective:*** *This study aims to assess the impact of using a digital educational game on graphs in teaching and learning this topic. Hence, we present* Missão Aspirapó*, a mobile digital game for Android developed with this purpose.* ***Methodology or Steps****: The methodologies Learning Design and* Programa de Avaliação de Jogos Digitais Educacionais *were used, respectively, for the creation and evaluation of the game.* ***Results:*** *The results indicate that the game has a learning potential between high and very high, making it a viable educational tool, but with some opportunities for improvement.*
Keywords *Digital Educational Games, Game Evaluation, Graph Theory, Hamiltonian Graphs, Graph Planarity.*

1. Introduction

Nowadays, evidences suggest that students are spending more time playing games than studying with traditional methods. Therefore, educational institutions and professors have the responsibility of exploring new teaching and learning methodologies that employ these technologies to their advantage [Tobias et al. 2014].

In computer science, solving mathematical and logical problems has always been a task that many students struggle with. This difficulty occurs because these problems frequently require a high level of abstraction or are loosely related to daily-life situations. Educators state that student-professor interactions are a key factor in learning. However, in many cases, due to the size of classes and the variety of students' learning needs, these interactions are scarce. These obstacles, when not perceived and solved quickly enough, lead to high rates of failure and dropout [Raabe and Silva 2005].

In graphs, a subarea of computer science, students face many learning challenges. Some of these challenges are translating written mathematical notation into visual models, recognizing the same object when shown in different representations, and memorizing graph theory terminology [Lucas 2017].

As described in Section 2, other authors have already proposed digital games related to graph theory. In summary, existing games exercise the following concepts:

graph definition, shortest path, breadth-first search, depth-first search, coloring, and planarity. Furthermore, it is relevant to mention that, among the related work researched, there is a lack of focus on digital educational games about graphs available as native mobile applications.

In this way, it is clear that the learning process is going through a change and incorporating the new technologies into it. At the same time, challenges for teaching computer science, specifically with graphs, create a favorable environment for exploring new learning methodologies, such as the use of games for teaching. Therefore, it is a relevant research problem to evaluate whether the use of a digital educational game on graphs could have a positive impact on learning and teaching this subject. The objective of this study is to create an educational digital game on graphs and evaluate its learning potential as a support tool to learn this subject. The idea is to create a *mobile* game that explores the concepts of Hamiltonian and planar graphs, since both this platform and these concepts have not yet been put together in a game according to our knowledge.

The remainder of this article is structured as follows. In Section 2 the related work is reviewed. In Section 3 the theoretical background is presented. In Section 4 the methodology is described. In Section 5 the development of *Missão Aspirapó* is detailed. In Section 6 the results are discussed, and, finally, in Section 7, the conclusions are drawn.

2. Related work

When it comes to games aimed at teaching and learning graphs, several works have already been published. This section reviews games related to the present work, while specifying their platforms and the associated graph theory concepts. The main differences between previous games and the one introduced in this paper are discussed.

The Google Scholar Research Tool was employed to find related work. For that, only papers from the last five years were considered and the following search strings (and their respective translations to Portuguese and Spanish) were used: *game* and *education* and *graph* and *theory*, *game* and *education* and *graph* and (*app* or *algorithm*), *game* and *graph* and (*planar* and *puzzle* or *eulerian*), *gamification* and *education* and *computational thinking*.

Considering games that run only on desktops, four games were found. *Graph Defender* [Pavani et al. 2023] and *Formigas em Grafo* [Santos and Ferreira 2021] explore the breadth-first search and depth-first search algorithms, and are intended to be used as an educational tool inside universities. *Swap Planarity* [Kraaijer et al. 2018] is a game that exercises the concept of planar graphs, while *Finding the Shortest Path by a Greedy Algorithm* [Tsarev et al. 2023] is a game that focuses on the concept of shortest paths. Both of these games do not target a specific audience.

Among native mobile applications are the games *Cadê Minha Pizza?* [Honda et al. 2022a] and *StarDust* [Melo et al. 2019]. Both games exercise the concept of shortest paths, the first one being aimed at high school students, and the second one being recommended to all publics.

With respect to web applications, we have the game *Mestre dos Grafos* [Martins 2023]. It teaches and practices primarily the concept of graph coloring and secondarily the concepts of Hamiltonian and Eulerian graphs. The target audience consists of technician-

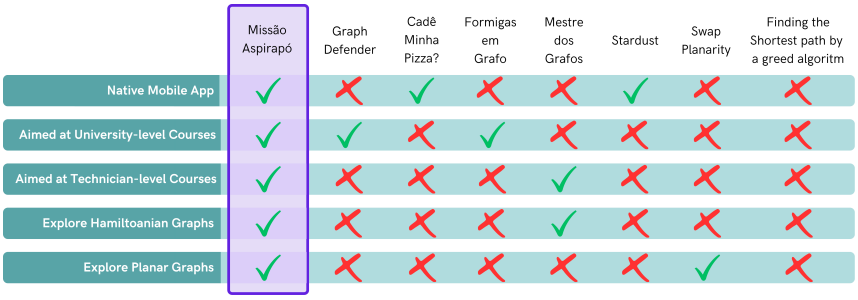

Figure 1. Comparison between Missão Aspirapó and related games

level students. *Mestre dos Grafos* actually lies in a sort of gray area, between mobile and web applications, since it was developed as a web application meant to be used on smartphone browsers. It is worth mentioning that even though web applications are more accessible and updatable due to their characteristic of running remotely on a server, this type of application has some setbacks, such as poorer performance and user experience.

In summary, regarding graph theory games, a lack of focus on mobile platforms can be observed: only 28.57% of the games reported above are native mobile applications. Considering the downsizing that devices are going through nowadays [Oliveira 2008], and that mobile devices are increasingly more accessible to students, it becomes clear the need for developing native mobile games to aid teaching and learning graph theory subjects.

The game presented in this article, called *Missão Aspirapó*, was developed as a native mobile application and aims to engage students of computer science that are starting their studies in graph theory. The game targets both university-level students, who study graph theory with greater depth, and technician-level students, who study the topic at a more basic and introductory level. Missão Aspirapó explores and practices the concepts of planar graphs and Hamiltonian cycles, concepts that have not yet been exercised together by any of the related games. Moreover, the present work contributes with another tool and experiment in regard to teaching and learning a difficult topic such as graph theory, an area that still has plenty of space for research efforts. In Figure 1, a comparison between Missão Aspirapó and the related games elucidates the differentials brought to the community by this paper.

3. Theoretical Background

The key concepts for the creation of Missão Aspirapó are presented in this section. These concepts provide the foundation for a digital game for teaching and learning graphs.

3.1. Gamification

In his book, Kapp [2012] not only defines the concept of gamification, but also describes its nuances and different perspectives. For the author, gamification consists in using the mechanics, esthetics, and strategies of games to engage people, motivate them, and promote learning and solving problems. For Orlandi et al. [2018], gamification emerges as an alternative that in many ways captivates the interest of students, generates curiosity, and brings together elements that improve participation and engagement, reinventing the learning process.

In the Brazilian educational scenario, Bahia and Carvalho [2024] state that gamification is a mechanism capable of going against the lack of interest and distraction of the students in class. For the authors, nowadays, games have been achieving high rates of engagement, being capable of retaining the students' attention and thus contributing to the learning process. For these reasons, Bahia and Carvalho [2024] regard gamification as a process that should be reassured and incorporated into schools.

The conception of Missão Aspirapó is based on the understanding that the gamification of learning activities can engage students and retain their attention [Bahia and Carvalho 2024]. Once the students are more focused on the activity, they can obtain better results on it.

3.2. Graph Theory Concepts

A *graph* G is an ordered pair (V, E), in which E is a subset of $V \times V$ with unordered pairs from V. A graph is commonly finite, which means that both sets V and E are finite. The elements of V and E are called *vertices* and *edges*, respectively. Two vertices $u, v \in V$ are neighbors if there is an edge $\{u, v\} \in E$. A *walk* in G is a sequence $v_0 v_1 \dots v_k$ of vertices of G such that, except for the first vertex, each vertex is a neighbor of its predecessor. A *cycle* in G is a walk $v_0 v_1 \dots v_k$ in G such that $k \geq 3$, $v_0 = v_k$ and all the vertices $v_0 v_1 \dots v_{k-1}$ are different [Bollobás 1998].

A graph is *Hamiltonian* if it has a *Hamiltonian cycle*. This concept refers to a cycle that includes all the vertices of the graph. A graph is *planar* if it can be drawn in the plane in such a way that the edges do not cross themselves [Bondy and Murty 2008]. One of the key elements of Missão Aspirapó is the interesting class of graphs that are at the same time Hamiltonian and planar. When dealing with this class, it is useful to know Grinberg's Theorem [Grinberg 1968], which shows a necessary condition for a planar graph to be Hamiltonian, and Tuttes' Theorem [Tutte 1956] (extended by Thomassen [1983]), which proves a sufficient condition for the same statement.

4. Methodology

Two methodologies were followed to create and evaluate Missão Aspirapó. *Learning Design* [Honda et al. 2022b] was used for the game creation and *Programa de Avaliação de Jogos Digitais Educacionais* (PAJDE) [Santos 2018] was employed for its evaluation.

In general, *Learning Design* is a methodology for guiding the creation of digital educational games. It was proposed by Honda et al. [2022b], and consists of three stages: conception, ludification, and evaluation. The first stage, *conception*, occurs before the creation and implementation of the game. Here, some aspects of the game are defined, such as the learning problem, theme, target audience, and initial idea. This is the stage in which the motives behind creating a digital educational game are acknowledged. The second stage, *ludification*, is when the game is actually carefully thought out and planned. For that, in this stage, it is necessary to create a story for the game, create its game play, its learning mechanics, its level design, and the rhythm graphic. The last stage, *evaluation*, focuses on developing and validating the proposed game. In that sense, the game should be first prototyped, so that it can be later implemented within the chosen game engine, and finally be tested with its target public. For testing, it is required to choose an educational game evaluation methodology, such as PAJDE [Santos 2018] or MEEGA+ [Petri et al.

2019], and apply it with the target public after they have tested the game. That way, the game will not only be implemented, but will also go through an evaluation with its target audience, which will reveal how effective it actually is.

As already mentioned, PAJDE is a methodology created by Santos [2018] to evaluate digital educational games. With this tool, it is possible to infer quantity and quality aspects of a game and then assess if the game has a high or low potential to help the learning process. In general, the methodology consists of applying a questionnaire with the target public after they test the game for some time. In this questionnaire (using the Likert scale [Likert 1932]), the following aspects of the game will be evaluated: immediate feedback, learning objectives, narrative, interactivity level, concept integration, learning curve, collaborative practice and level of challenge. Finally, with all the answers from the questionnaire converted into decimal numbers, by applying a mathematical model, it is possible to generate a Learning Potential (LP) score of the game. Then, with this score, based upon a scale, it is possible to see if the game has a very low LP, a low LP, a moderate LP, a high LP, or a very high LP.

As stated before, the *Learning Design* methodology was used for creating Missão Aspirapó. Going through the methodology steps, when the moment for the testing with the target public came, the PAJDE methodology was employed. Furthermore, still regarding the evaluation, it occurred in two different moments with two different groups. The first moment was at Instituto Federal de Santa Catarina (IFSC), with a class from the Systems Development Technician Course Integrated to High School. The evaluation was carried out in a classroom setting with 12 students. The second moment was at Universidade Federal da Fronteira Sul (UFFS), with a class from the Bachelor of Computer Science course. The evaluation occurred in a classroom context with 22 students. It is important to register that both experiments were acknowledged by the ethics committee of our institution and that no ethical process was required since no personal-sensible data were collected.

5. Missão Aspirapó

Missão Aspirapó is a mobile digital game, developed as a tool to help learning and teaching graphs. In the game, the players use a vacuum cleaner robot to vacuum a house, visiting exactly once each room.

5.1. Conception

Following the first step of the *Learning Design* methodology, a brainstorm was held to define the theme, problem, target public, and initial idea for the game. The theme chosen was graph theory, with the associated problem being the struggles for learning this content, and the target audience being students that are starting their studies in this subject. The initial idea consisted of an abstraction of a houseplant as a graph, in which each room represented a vertex, and the doors, the edges. The objective of the game would be to vacuum all the rooms in the house without going twice through the same room, which translates into finding and going through a Hamiltonian cycle. In addition, because of the planar aspect of houseplants, the graph abstractions would always correspond to a graph that is not only Hamiltonian, but also planar. Therefore, the two concepts of the graph theory used in the game were defined: Hamiltonian cycles and planar graphs.

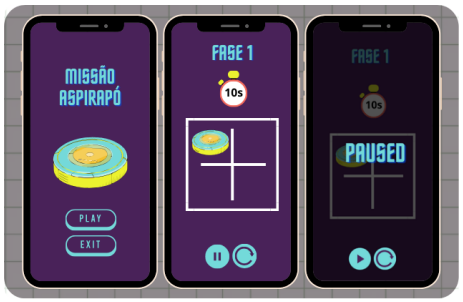

Figure 2. Prototypes of the game

Figure 3. Game menus

5.2. Ludification

Next, in the ludification step of *Learning Design*, with the game mechanics already defined, the focus was on building the narrative of the game. For that, a vacuum cleaner robot called "xpto" was chosen as the main character. In general, the story of the game is centered on helping this vacuum cleaner robot vacuum all the rooms of a house. To increase the challenge of the game, a time limit for cleaning the house was introduced, justified by the bad battery the robot has. In addition to that, the different levels of the game (level design) were planned on an logic of growing difficulty, making each higher level more complex and adjusting the time limit to fit it.

5.3. Evaluation

5.3.1. Prototyping

In the evaluation step, game prototypes were developed using the Canva [2024] design tool (Figure 2). After the creation of these prototypes and the design of all the houseplants for the different levels of the game, it became possible to map precisely all the illustrations needed for the game. With help from the Spanish artist Sergio Río Lavín, all the prototyped arts were adapted, resulting in a unique and modern aesthetic for the game. This collaborative process was fundamental to guarantee that the game had a cohesive, distinguished, and attractive visual identity, improving the user experience.

5.3.2. Development

Still in the evaluation step of *Learning Design*, the implementation of Missão Aspirapó was carried out using Unity Technologies [2024], a 2D and 3D game engine, based on the programming language `C#`. During the coding of the game, simple code practices were used, since the idea for this project was not only to conceive a complete game, but also to evaluate its learning potential. This aspect can also be observed in the user experience provided by the game, in which the menus and buttons are concise and direct. For that reason, the game became easier to get around and play with. Missão Aspirapó is available for download on the Brazilian Google Play Store, and can be installed on mobile devices with Android [Google 2024] operating system in version above or equal to 10.0.

Figure 4. Level 1 Screens

Figure 5. Error Screens

5.3.3. Game demonstration

In this section, a game demonstration of Missão Aspirapó is shown, from the moment when players access the initial menu, go through all levels, and finish the game, to the final moment when they access the game curiosities. The initial menu, shown on the left of the Figure 3, offers simple options for the player: start the game, access the curiosities, or leave the app. On the other hand, the level menu, shown on the right of the same figure, allows the user to navigate between levels, according to the ones they have already gone through. When the player presses "jogar" on the initial menu, they are redirected to the level menu. If this is not their first time playing Missão Aspirapó, they will be able to choose the level they want to play. Otherwise, the only available option will be the tutorial, which explains the narrative and functioning of the game. At the end of the tutorial, the player must complete a test level of the game to make sure that they are prepared. Figure 4 illustrates the first level of the game, in which the player, controlling the vacuum cleaner robot, needs to clean all rooms of the houseplant and get back to the initial point.

During this path through the houseplant, the game validates many things to avoid that a room gets cleaned more than once or that the player is able to move between rooms that are not connected. If the player tries to enter rooms that are not connected, a pop-up error is shown with the message "Cômodos não conectados". If the player cleans the same room twice, they will be redirected to the game over screen, with a message explaining what happened. The same happens if the robot battery dies, but only a different message is displayed. Figure 5 illustrates all of these situations.

If the player vacuums all of the rooms within the time limit, they will go to the next levels. The game has seven levels with increasing difficulty, in which the player will be able to practice concepts from the graph theory to find the Hamiltonian cycles in the houseplants.

When they complete all levels, the player is redirected to the victory scene (Figure 6), where they will be congratulated on winning and invited to learn more about the educational aspects of Missão Aspirapó.

Lastly, on the curiosity scenes, illustrated in Figure 7, information about the concepts used on Missão Aspirapó is shown. In a simple way, the concepts of graph, Hamiltonian cycle, and planar graphs are explained. The objective behind this is to present the theoretical foundation for the exercise made with the game.

Figure 6. Victory Screens

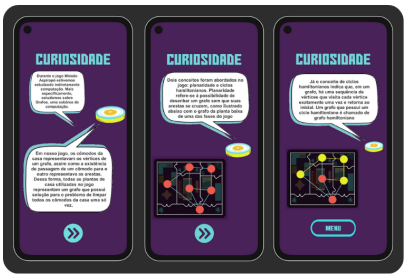

Figure 7. Curiosity Screens

6. Results and Discussion

This section is reserved to describe and discuss the results of the Missão Aspirapó evaluations that were made using the PAJDE questionnaire [Santos 2018, Figure 4.17].

6.1. Evaluation at IFSC

Analyzing the results obtained at IFSC, in Figure 8, it can be observed the responses that students gave on each question of the PAJDE questionnaire. Each question is closely associated with an aspect of the game, and it is answered using the Likert [1932] scale (translated into Portuguese): “Completely disagree”, “Disagree”, “Neutral”, “Agree” and “Completely agree”.

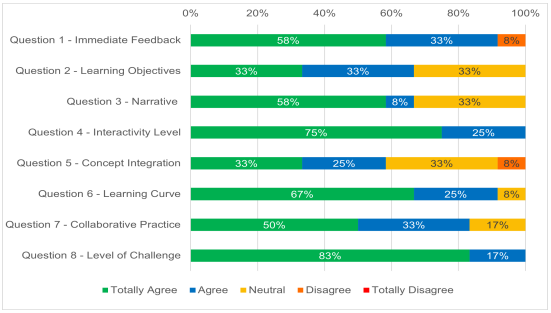

Figure 8. Answers – Evaluation IFSC

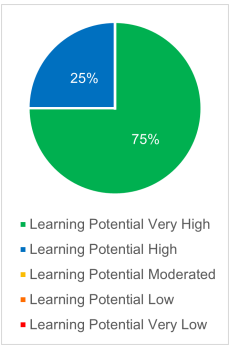

Figure 9. LP – IFSC

In general, Missão Aspirapó had a positive evaluation at IFSC. The immediate feedback was positively evaluated by 91% of the participants, while the interactivity level scored only positive responses (with 75% of “Totally agree” and 25% of “Agree”). The learning objectives received mixed evaluations, suggesting that they could be improved. The narrative was well received (with 58% of “Totally agree”), the same as the learning curve with 66%. Although collaborative practice was not a focus on game design, it received favorable responses (50% of “Totally agree”). Finally, the level of challenge of the game was complimented, with 83% of the students indicating the highest level of satisfaction.

Lastly, calculating the LP indicated by each of the students interviewed, hence the graph in Figure 9. In it, it is possible to observe that 75% of the students said that Missão Aspirapó has a very high LP, while 25% indicated a high LP. These data reassure the viability of the game as an educational tool for teaching graphs, and point out as positive aspects the immediate feedback, narrative, interactivity level, learning curve, and

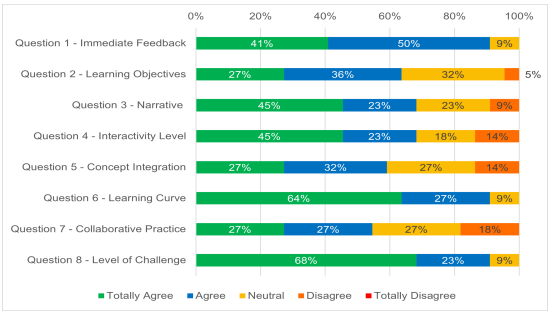

Figure 10. Answers – Evaluation UFFS

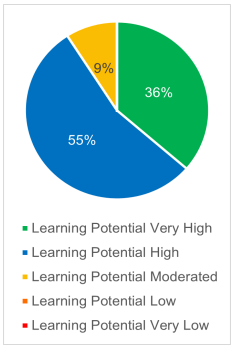

Figure 11. LP – UFFS

challenge levels. However, learning objectives, concept integration, and collaborative practice could be improved.

6.2. Evaluation at UFFS

Observing now the results obtained from the evaluation at UFFS, in Figure 10, it is possible to see the answers of the students for each question in PAJDE questionnaire. All of these graphs are presented on the same scale as mentioned before.

Once again, Missão Aspirapó received a positive reception from the students. The immediate feedback, the learning curve, and the level of challenge were all well rated with 91% of the responses being positive. The narrative and interactivity level were considered satisfactory, but with some room for improvement. When it comes to learning objectives, the answers were more spread out, suggesting that the implicit approach of the game can be difficult to perceive. Collaborative practice, although it was not a focus, received neutral positive evaluations, possibly due to spontaneous interactions between students.

In conclusion, when the LP is calculated for each of the participants from UFFS, the graph in Figure 11 is generated. In it, it is possible to see that 55% of the students reported that Missão Aspirapó has a high LP. Alternatively, 36% indicated that the game has a very high LP and 9% pointed out that the LP for the game is moderated. Although these results are not as positive as the one obtained at IFSC, it still indicates that the game has a high LP, suggesting that it could actually contribute to teaching graph theory. In addition to that, the evaluation from UFFS highlights that some strengths of the game are its narrative, interactivity level, learning curve, and level of challenge. At the same time, aspects such as learning objectives, concept integration, and collaborative practice could be improved.

6.3. Comparative analysis between the evaluations at IFSC and at UFFS

When the results of the evaluations of Missão Aspirapó at IFSC and at UFFS are compared, a great similarity can be seen. Both groups identified the same strengths and weaknesses in the game. Beyond that, with regard to the LPs, both in the evaluations at IFSC and at UFFS, a very high and high LP were the predominant responses, showcasing the potential the game has for teaching and learning graph theory.

The data from the evaluation at UFFS is more spread, with more neutral and positive evaluations, compared to the evaluation at IFSC, which is understandable, given

that the number of participants in the UFFS's research almost doubles. In addition, the educational level difference between the students of IFSC, who are in high school, and the ones from UFFS, who are in university, could explain the difference in evaluations. That is most likely because students from UFFS, with more experience, have standards for evaluating that are further developed because of the formative aspect of the Bachelor of Computer Science degree, while students from IFSC are on a technician course, focused on the bases of computer science. Therefore, considering both evaluations, out of the 34 students interviewed, 17 indicated that Missão Aspirapó has a very high LP, 15 pointed a high LP and 2 a moderated LP. These results show that the game developed is an educational tool viable for teaching and learning graphs, with some space for improvements, but still capable of helping since now on the study of graph theory.

7. Conclusion

With this paper, Missão Aspirapó was presented, a digital mobile game to help teach and learn graphs. Exploring a new combination of graph theory concepts, when compared to its competitors, the game focuses on graphs that are both planar and Hamiltonian. The idea of the game is for the player to use a vacuum robot to vacuum a house, visiting exactly once each room of the place.

The *Learning Design* methodology was used to create the game and among the many steps followed, when it came to the evaluation phase, the PAJDE methodology was used to measure the learning potential of the game. Still, regarding the evaluation step, two groups were able to test the game and respond to the PAJDE questionnaire, the first being a technician course class, and the second a university course class.

The results show that Missão Aspirapó has a learning potential between high and very high. Among the product advantages are immediate feedback, narrative, interactivity levels, learning curve, and level of challenge. Meanwhile, some of the improving points are learning objectives, concept integration, and collaborative practice. These data show that the game presented in this article is a viable tool for teaching and learning graphs, although it still has room for growth.

The main limitation of the current article could be the size of the sample used for the evaluation, since only 34 students participated in it. In addition, it is interesting to mention that both methodologies used for creating and evaluating Missão Aspirapó have been previously used and tested, therefore guaranteeing its scientific standards. For future work, it is aspired to improve the game based on what was learned with the evaluation described in this paper. For instance, some opportunities are implementing a feature for shared records, adding more graph theory explanations during the gameplay, and changing a bit the narrative of the game for its educational aspects to be clearer.

In summary, this paper not only presents a new game for learning graph theory with a combination of concepts not previously explored by competitors in mobile native platforms, but it also brings an academic support for the app, which, through the evaluations made, was considered a viable tool for its purpose.

References

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, New York.

Bondy, A. and Murty, U. S. R. (2008). *Graph Theory*. Springer.

Canva (2024). Canva official website. URL `https://www.canva.com/`. Accessed 11 October 2024.

Google (2024). Android official website. URL `https://www.android.com/`. Accessed 11 October 2024.

Grinberg, E. (1968). Plane homogeneous graphs of degree three without hamiltonian circuits. *Latvian Math. Yearbook*, 4:51–58.

Honda, F., Pires, F., Pessoa, M., and Maia, J. (2022a). Cadê minha pizza? Um jogo para exercitar matemática e pensamento computacional através de grafos. In *Anais Estendidos do XXI Simpósio Brasileiro de Jogos e Entretenimento Digital*, p. 876–885, Porto Alegre. SBC.

Honda, F., Pires, F., Pessoa, M., and Melo, R. (2022b). Aplicando learning design na ludificação de percurso em grafos: uma jornada de aprendizagem. In *Anais do XXXIII Simpósio Brasileiro de Informática na Educação (SBIE 2022)*, p. 609–620, Porto Alegre. SBC.

Kapp, K. M. (2012). *The Gamification of Learning and Instruction: Game-Based Methods and Strategies for Training and Education*. Pfeiffer, San Francisco.

Kraaijer, R., van Kreveld, M., Meulemans, W., and van Renssen, A. (2018). Geometry and generation of a new graph planarity game. In *2018 IEEE Conference on Computational Intelligence and Games (CIG)*, p. 1–8.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 140(22):5–55.

Lucas, T. M. (2017). Grafos no ensino médio: uma proposta de atividade. Dissertação (mestrado), Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes.

Martins, F. S. (2023). Mestre dos grafos: uma possibilidade educacional baseada no conceito de gamificação para auxílio à aprendizagem da teoria dos grafos. Dissertação (mestrado), Instituto Federal do Espírito Santo, Vila Velha.

Melo, R., Silva, D., and Pires, F. (2019). StarDust: um serious game para a aprendizagem implícita de grafos. In *Anais dos Workshops do Congresso Brasileiro de Informática na Educação*, volume 8, p. 1237.

Oliveira, R. d. (2008). *Design multi-dispositivo em contextos de uso alternado e migração de tarefas*. Tese (doutorado), Universidade Estadual de Campinas, Campinas.

Orlandi, T. R. C., Duque, C. G., Mori, A. M., and Orlandi, M. T. d. A. L. (2018). Gamificação: uma nova abordagem multimodal para a educação. *Biblios Journal of Librarianship and Information Science*, (70):17–30.

Pavani, R. B., Junior, M. M. C., 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 Estendidos do XXII Simpósio Brasileiro de Jogos e Entretenimento Digital*, p. 536–547, Porto Alegre. SBC.

Petri, G., Wangenheim, C. G. v., and Borgatto, A. F. (2019). MEEGA+: Um modelo para a avaliação de jogos educacionais para o ensino de computação. *Revista Brasileira de Informática na Educação*, 27(03):52–81.

Raabe, A. L. A. and Silva, J. M. C. d. (2005). Um ambiente para atendimento as dificuldades de aprendizagem de algoritmos. In *Anais do XIII Workshop sobre Educação em Computação*, p. 2326–2337, Porto Alegre. SBC.

Santos, A. V. and Ferreira, A. B. (2021). Formigas em grafo: Um jogo educacional para apoio ao ensino e aprendizagem dos algoritmos de busca em largura e busca em profundidade. In *Anais da Escola Regional de Computação do Ceará, Maranhão e Piauí (ERCEMAPI)*, p. 59–66, Porto Alegre. SBC.

Santos, W. d. S. (2018). *PAJDE: um modelo de avaliação para jogos digitais educacionais*. Tese (doutorado), Centro Universitário SENAI CIMATEC, Salvador.

Thomassen, C. (1983). A theorem on paths in planar graphs. *Journal of Graph Theory*, 7 (2):169–176.

Tobias, S., Fletcher, J. D., and Wind, A. P. (2014). Game-based learning. In Spector, J. M., Merrill, M. D., Elen, J., and Bishop, M. J., editors, *Handbook of Research on Educational Communications and Technology*, p. 485–503. Springer, New York.

Tsarev, R., Azizam, S. H., Sablinskii, A., Potekhina, E., Gogoleva, I., Nikolaeva, I., and Ikonnikov, O. (2023). Gamification of the graph theory course. Finding the shortest path by a greedy algorithm. In Silhavy, R. and Silhavy, P., editors, *Networks and Systems in Cybernetics*, p. 209–216, Cham. Springer.

Tutte, W. T. (1956). A theorem on planar graphs. *Transactions of the American Mathematical Society*, 82(1):99–116.

Unity Technologies (2024). Unity – real-time development platform. URL `https://unity.com/`. Accessed 11 October 2024.