A Serious Game for Students with Math Learning Difficulties: Co-design-based Development and User Experience Evaluation Study

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Abstract: Teaching and learning mathematics is still considered complex by teachers and students. The objective of this study was to develop and evaluate the *Dyscalc Game*, a serious game for mobile devices to support the teaching and learning process of individuals with learning difficulties in basic mathematics, including those with dyscalculia. The implementation of game elements and mechanics was carried out based on recommendations from the literature and collected from a co-design process. The game was evaluated by professionals and students regarding usability and user experience, using the User Experience Questionnaire (UEQ). The results were above average for the UEQ scales in its benchmark. The game developed in this study demonstrated potential to be useful for both professionals and students.

Keywords: Mathematics. Serious Games. Specialized Educational Services.

Um Jogo Sério para Estudantes com Dificuldade de Aprendizagem em Matemática: Estudo de Desenvolvimento Baseado em Co-design e Avaliação de Experiência do Usuário

Resumo: Ensinar e aprender matemática ainda é considerado complexo por professores e alunos. O objetivo desse estudo foi desenvolver e avaliar o *Dyscalc Game*, um jogo sério para dispositivos móveis para apoiar o processo de ensino e aprendizagem de indivíduos com dificuldades de aprendizagem da matemática básica, incluindo aqueles com discalculia. A implementação dos elementos e mecânicas de jogo foram realizadas baseando-se em recomendações da literatura e por um processo de co-design. O jogo foi avaliado por profissionais e estudantes em relação à usabilidade e experiência do usuário, utilizando o *User Experience Questionnaire* (UEQ). Os resultados foram acima da média para as escalas do UEQ em seu *benchmark*. O jogo desenvolvido neste estudo demonstrou pontencial para ser útil tanto para profissionais quanto para alunos.

Palavras-chave: Atendimento Educacional Especializado. Jogos Sérios. Matemática.

1. Introduction

During the process of teaching and learning mathematics, difficulties arise among students in different age groups and teaching modalities. Some of these difficulties observed in schools are common to different subjects, but when it comes to mathematics, it is highlighted (Masola and Allevato, 2019) the lack of: motivation to learn the content and interest from students, and innovative, contextualized and interdisciplinary teaching strategies from teachers. Among such difficulties, there is also a Learning Disability (DL) characterized as a specific mathematics learning disorder, named Developmental Dyscalculia, or just Dyscalculia (Košč, 1974). It is related to difficulties in learning and understanding mathematics, as it reflects cognitive disability (Butterworth; Varma and Laurillard, 2011) in understanding quantity relations and the four fundamental operations (Association, 2014).

Numerical skills are essential in the daily lives of human beings. They are used daily in personal relationships. If, for any reason, there is a limitation in the development

of the learning process, in the ability to understand numbers and calculations, there will be a negative impact on the school and professional experience and on the individual's self-esteem (Monei and Pedro, 2017). These mathematics learning difficulties, including dyscalculia, influence the student's academic performance.

As a consequence, according to data from the main Brazilian basic education assessment exam, the *Sistema Nacional de Avaliação Educacional da Educação Básica* (SAEB), results of elementary school mathematics proficiency performance have consistently been below the national average (Santos and Tolentino-Neto, 2015; Santos and Alves, 2016). Therefore, it is clear that there is a need for purposeful solutions that contribute to improving students' performance in mathematics.

Serious Games are those computer games and simulation approaches and/or technologies in which the main purpose is not purely fun, being aimed at different areas, such as education and health (Ekin; Polat and Hopcan, 2023). Thus, serious games are developed to promote some change in the player, such as knowledge and cognitive capacity, without entertainment being the main focus. Serious games have been used as a digital intervention in several neurodevelopmental disorders (Vacca *et al.*, 2023).

Smartphones can be a tool to support the teaching and learning process within the classroom to improve students' academic results (Calderón-Garrido; Ramos-Pardo and Suárez-Guerrero, 2022). We believe that the use of serious games on mobile devices in the classroom can be an alternative to support the mathematics teaching and learning process. We accept as true that a serious game can bring motivation and interest in mathematics to students.

This study aimed to develop and evaluate a serious game for mobile devices to help the teaching and learning process of students with difficulties in learning basic mathematics, including those with dyscalculia. The *Dyscalc Game* was developed based on requirements identified in the literature and a co-design process. The evaluation focused on usability and user experience, with the participation of health and education professionals, as well as students.

The remaining of this paper is organized as follows. Section 2 describes the methodology with all steps performed in this study, including the co-design and development of the *Dyscalc Game* as well ass its evaluation, while Section 3 presents the results. In Section 4, we discuss the principal findings, compare the proposed game with prior work, and acknowledge limitations. Finally, we derive our conclusions in Section 5.

2. Materials and Methods

The methodology used in this study consisted of carrying out the following steps: (1) development of the game prototype; (2) conduction of co-design process; (3) improving the serious game based on the new requirements identified; and (4) conduction of experimental evaluations regarding usability and user experience. Figure 1 depicts the methodology steps organized in semesters.

Free and Informed Consent/Assent Forms, when applied, were signed by all participants. The research project was approved by the Research Ethics Committee of the Parnaíba Delta Federal University under number 5.858.354.

2.1. Prototype Development

Initially, based on a bibliographical search and analysis, the studies by Cezarotto and Battaiola (Cezarotto, 2016; Cezarotto and Battaiola, 2017; Cezarotto, 2019) were identified. They proposed recommendations to be used in the implementation of

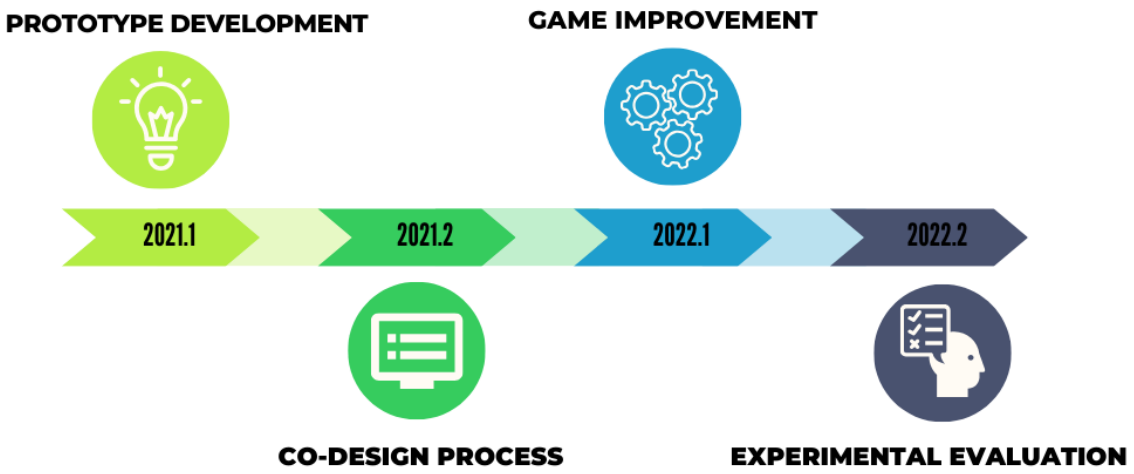


Figure 1. Research methodology timeline with the four steps.

serious games used as an intervention for dyscalculic students. We then used the recommendations to guide the game development.

We began creating and defining the game genre, storyline, characters, scenarios, and mechanics that would attract and motivate players, as well as the engine to develop the game. We defined the genre as action, and the sub-genre as platform game (a.k.a., platformer), inspired by Super Mario World/Bros and Sonic. Games in this category are characterized by being those in which players control a character who should walk/run and jump across platforms and obstacles, collecting objects and facing challenges. We believe that children/young players find it easier to learn and understand the game's proposal, play it in mobile devices (e.g., smartphones, tablets), and are attracted to its colors, sound effects, and stimulating adventure.

We implemented the first version of the game in the Unity 2D, considering different mechanics, such as the movements of the main character and secondary characters, sprites, soundtrack and sound effects, and gameplay. The storyline was based on a coexistence between animals in a forest, which has an environment full of beauty, which conveys good feelings and presents characters that can be sympathized with by players during the game. The storyline in a serious game is one of the ways to transmit the values desired by those who created it (Janssen *et al.*, 2019). As a result, we developed the initial prototype of the serious game *Dyscalc Game* for Android mobile devices with only one level and 22 math challenges.

2.2. Co-design Process

Co-design is a cooperation with the purpose of bringing together creative ideas for the development of a project, then involving researchers and stakeholders in a reflective process in search of a solution (Bird *et al.*, 2021). At this step, we sought to obtain ideas and suggestions with the participation of the following professionals: mathematics teachers, psychopedagogues, psychologists and game developers. Recruitment took place at *Associação de Pais e Amigos dos Excepcionais* (APAE) and municipal education departments in the cities of Araioses-MA and Parnaíba-PI, and at the IFMA/Campus Araioses.

We sought to include mathematics teachers with experience who worked (or had previously worked) in all teaching modalities (from elementary to high school). To select psychology professionals and pedagogues, we considered, as a selection

criterion, the professional experience working directly or indirectly with individuals with neurodevelopmental disorders. Game developers should have experience or knowledge in Unity engine.

First, we sent participants the initial game prototype and a participant characterization questionnaire to check if they met selection criteria. After two days, we then brainstormed with them to build a set of requirements to be implemented towards an improved version of the game. At the end, a list containing functional and non-functional requirements was created.

2.3. Game Improvement

Based on the considerations obtained during the co-design process, which allowed new requirements for the game to be raised, we began developing an improved version of the *Dyscalc Game*. Importantly, the requirements identified were specific, not requiring radical changes to the game design. There were changes to the game's initial screens and the distribution of challenges throughout each level. There was an addition of levels with different scenarios, sprites, game time, difficulty levels in each obstacle, and math challenges.

The database of the improved version of the game had a total of 100 questions (i.e., math challenges). The math challenges were: (a) prepared by the authors; and (2) taken from simulations and SAEB exams from the 9th year of elementary school. To prepare the math challenges, the SAEB descriptors were observed, which are subjects taken from specific mathematics themes from the 9th year of elementary school.

2.4. Experimental Evaluation

The serious game was then evaluated by professionals, who did not participate in the co-design process, and students. The purpose of the experiment was to evaluate the usability and user experience of the game. With a convenience sampling, participant recruitment was carried out at the municipal education departments in the cities of Araioses-MA and Parnaíba-PI. The following professionals met the selection criteria:

- Teachers licensed in mathematics who actively work in classroom teaching;
- Psychopedagogues who assist children and adolescents with neurodevelopmental disorders;
- Psychologists who treat patients (children and adolescents) with neurodevelopmental disorders.

Student participants had to be of both sexes, who met the following inclusion criteria: be literate and enrolled in the 1st grade of high school. Importantly, as the study was carried out in February, so the students were starting the school year. The following exclusion criteria were considered: students intellectually disabled, with autism spectrum disorder, motor disorders, bipolar disorder, obsessive-compulsive disorder, post-traumatic stress, who have hearing or visual impairments. Participant recruitment was carried out at the IFMA/Campus Araioses.

The procedure used with participants followed the following stages: (1) signing the forms for participation in the study; (2) play the game for a minimum period of 30 minutes and a maximum of 50, to ensure that participants could complete all game levels; and (3) questionnaire application. The questionnaire used to evaluate usability and user experience was the User Experience Questionnaire (UEQ) (Hinderks *et al.*, 2019), which allows the user to express feelings and impressions when playing the game. The questionnaire has 26 items organized into six aspects (i.e., scales), answered on a Likert scale from 1 to 7, which cover a comprehensive impression of user experience: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty.

To carry out the statistical analysis of the data collected with the application of the questionnaire, we used the UEQ data analysis tools (Hinderks; Schrepp and Thomaschewski, 2023). Results were compared with the UEQ benchmark (Hinderks *et al.*, 2019; Hinderks; Schrepp and Thomaschewski, 2023). To check the internal consistency for each UEQ scale, the values obtained for the Cronbach's Alpha coefficient (Bland and Altman, 1997) were analyzed.

3. Results

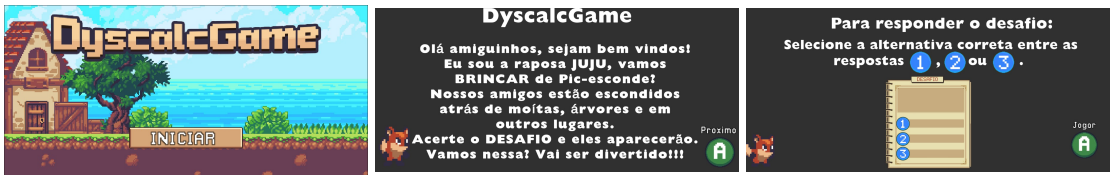
3.1. Co-design Outcomes

The following professionals participated in the co-design process: 4 mathematics teachers, 1 psychopedagogue, 1 psychologist and 2 game developers. They were aged between 25 and 45 (43±6.95). The professionals tested the game for two days and, from a brainstorming meeting, we identified the requirements, namely:

1. Increase the time of each level;
2. Reduce the number of math challenges in each level;
3. Improve the game's initial information, so giving the player more clarity about what the game is, what its purpose is and what must be done to complete the levels;
4. Increase the diversity of math challenges;
5. Allow adjustment of the level of math challenges;
6. Add a score at the end of each level;
7. Add characters and fun elements that encourage the use of the game.

3.2. Improved Version of the *Dyscalc Game*

The improved version was then implemented, seeking to meet the requirements identified in the co-design process. Figure 2 depicts the presentation screens of the improved version of the *Dyscalc Game* in Portuguese language.



(a) (b) (c)

Figure 2. *Dyscalc Game* screeshots: (a) Initial screenshot; (b) Welcoming screen; and (c) Game instruction for math challenges.

Figure 3 displays scenarios from three different levels of the *Dyscalc Game*. During the levels, the fox goes through different scenarios, involving forests and caves. We sought to involve the player more, by encouraging him/her to face the adventure of overcoming maths challenges. A summary video of the game is presented at: ⟨https://bit.ly/dyscalcgamerenote⟩

3.3. Usability and User Experience

3.3.1. Professionals

In total, 11 professionals (5 women) participated in the evaluation: 6 mathematics teachers, 2 psychopedagogues and 3 psychologists. They were aged between 27 and 50 (44±6.75), and had more than 3 years of experience in their areas of training. According to the UEQ data analysis tools, when there are three or more inconsistencies in an assessment between scales or many repeated answers, what is detected by the tool, we

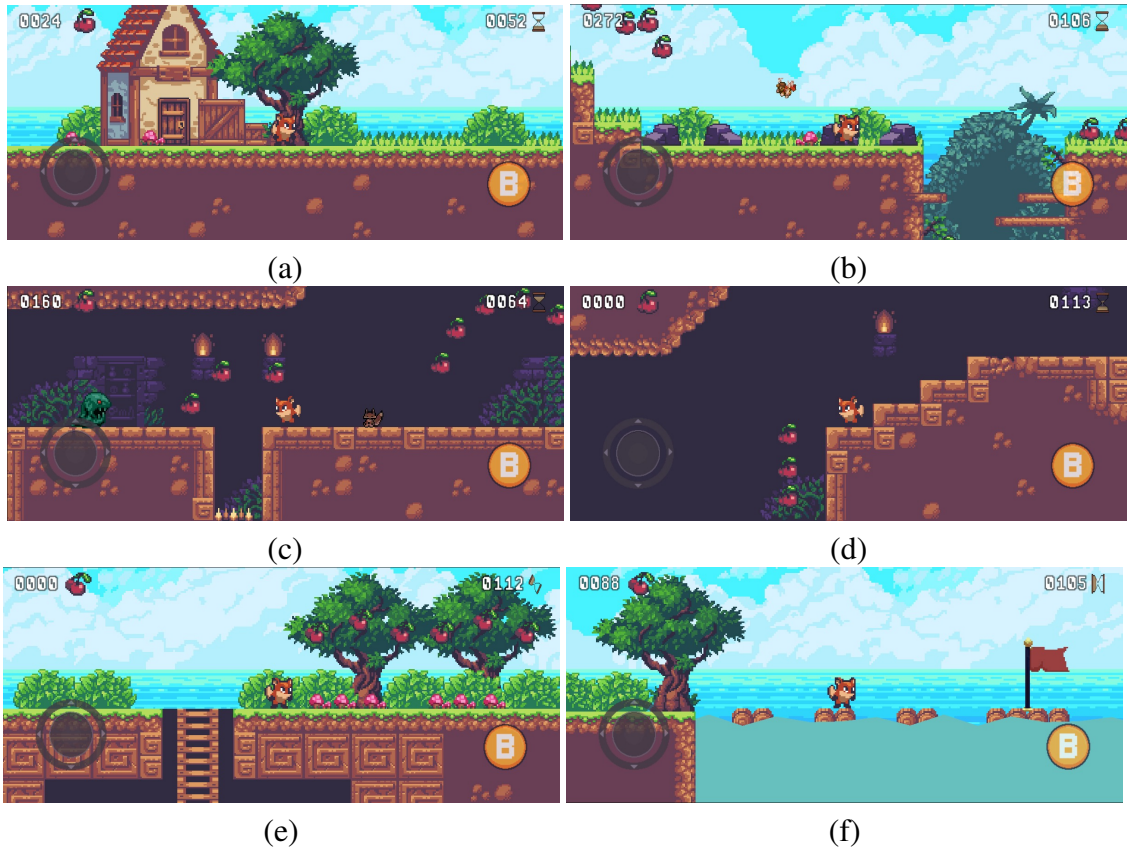


Figure 3. *Dyscalc Game* screeshots: (a-b) level 1; (c-d) level 2; and (e-f) level 3.

must remove the participant data from the analysis. We removed data of one participant from the analysis. Figure 4 shows the UEQ responses distribution, with predominantly positive and neutral evaluations by professionals.

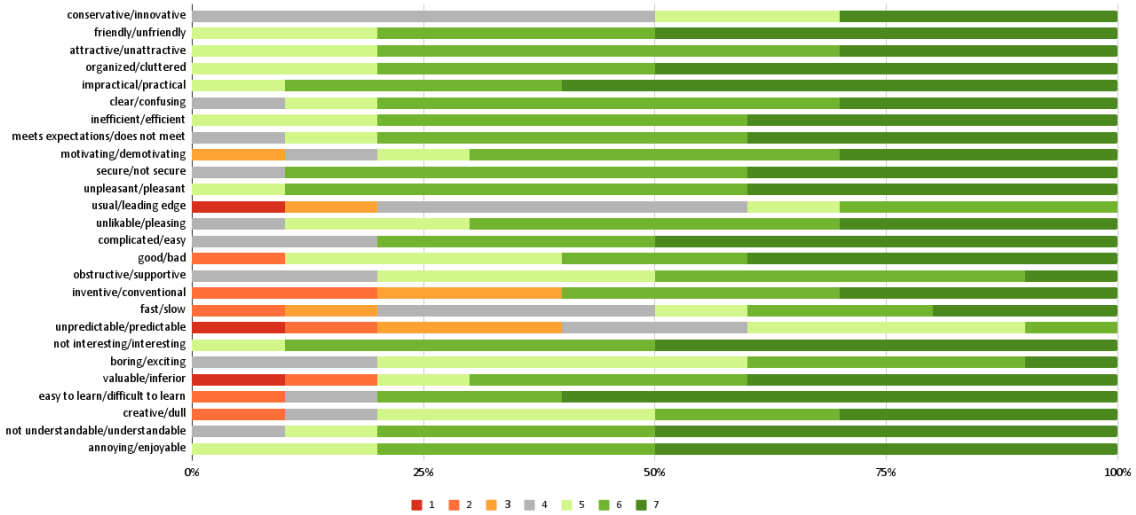


Figure 4. Distribution of UEQ responses for the six scales by professionals.

The UEQ benchmark is a reference for interpreting results obtained in previous user experience studies that used the UEQ questionnaire (Hinderks *et al.*, 2019; Hinderks; Schrepp and Thomaschewski, 2023). It is constantly updated and, in the version used to

analyze results (version 12), it has data from 468 studies with different products, carried out with 21,175 subjects, for comparison purposes. The benchmark provides information about the relative position of the evaluated product in relation to the average of other evaluated products, indicating if it is:

- Excellent: in the range of the 10% best results;
- Good: 10% of results better, 75% of results worse;
- Above Average: 25% of results better, 50% of results worse;
- Below Average: 50% of results better, 25% of results worse;
- Bad: in the range of the 25% worst results.

Figure 5 presents the evaluation results in the benchmark graph, where the averages per scale are shown: attractiveness (2.10 - excellent), perspicuity (2.08 - excellent), efficiency (1.95 - excellent), dependability (1.38 - above average), stimulation (1.70 - good), and novelty (0.93 - above average).

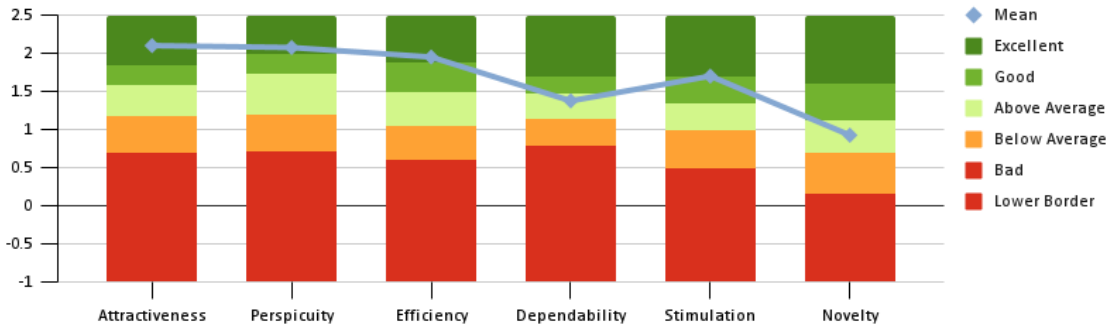


Figure 5. UEQ benchmark comparing the results of the *Dyscalc Game* with other software solutions - Responses from professionals.

3.3.2. Students

In total, 19 students (11 women) aged between 15 and 17 (15±0.69) participated in the study. We removed data of one participant from the analysis due to inconsistency issues. Figure 6 shows the distribution of responses by students.

Figure 7 presents the benchmark graph with the results for each scale: attractiveness (2.27 - excellent), perspicuity (2.15 - excellent), efficiency (2.13 - excellent), dependability (1.49 - good), stimulation (2.36 - excellent), and novelty (1.19 - good).

4. Discussion

4.1. Principal Findings

The co-design process was very important for us to arrive at an improved version of the proof of concept of *Dyscalc Game*. The suggestions were quite relevant. Without the collaboration of interested participants, the game would not have achieved results that we have considered promising.

By analyzing the results of the UEQ answered by professionals and students, we found that the *Dyscalc Game* is mostly classified as “excellent”. Therefore, we consider the results to be positive, with special attention to the attractiveness, transparency, perspicuity and stimulation scales. Although the dependability and novelty scales reached lower values, they were still above average. The benchmark result shows that, even with

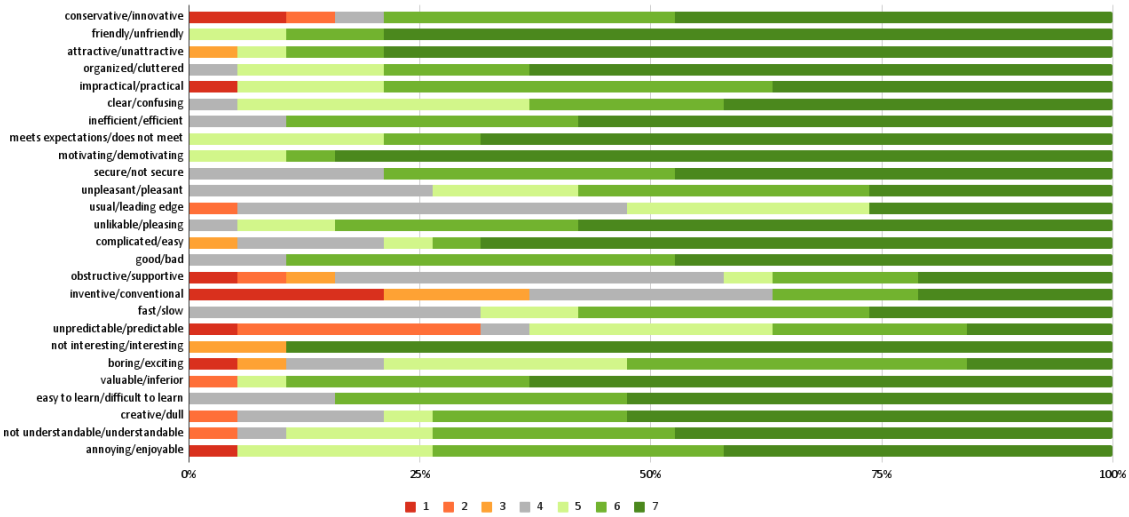


Figure 6. Distribution of UEQ responses for the six scales by students.

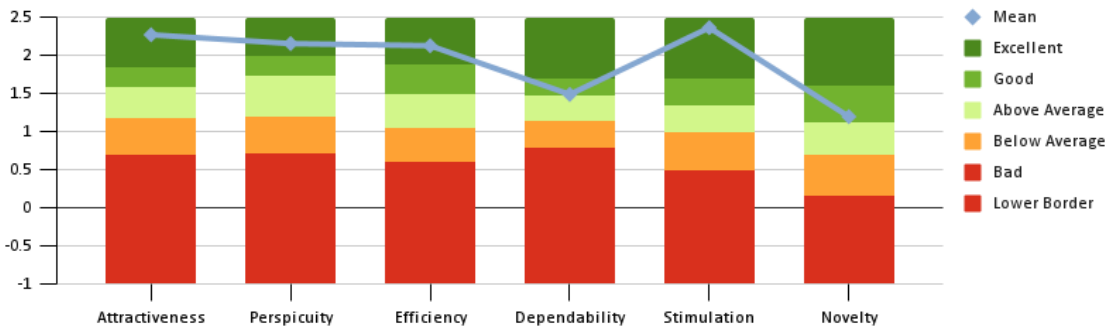


Figure 7. UEQ benchmark comparing the results of the *Dyscalc Game* with other software solutions - Responses from students.

the majority of scales classified positively, there are still opportunities to improve the game, mainly in the dependability and novelty aspects.

We should analyze these results carefully. First, we believe that the novelty aspect was not well evaluated as the game was inspired by already well-known games (Super Mario World/Bros and Sonic) and, therefore, it may not have presented participants with very innovative scenarios or game mechanics. Second, regarding the dependability aspect, it was directly affected by the fact that players could not control which level they would start playing in, with the need to always restart the game from the first level. This is an acknowledged limitation of the developed proof of concept. We will consider these results to improve future versions of the game, in order to improve usability and user experience.

4.2. Comparison With Prior Work

Different digital and non-digital interventions for teaching and learning students with difficulties in mathematics have been proposed and studied in the literature (Monei and Pedro, 2017; Avila; Lara and Lima, 2019). Some of the interventions are digital learning objectives proposed as serious games. Among them, several were developed to obtain knowledge in a specific mathematics content. For example, the game *D.O.M.* (Santos and Alves, 2016) addresses quadratic functions and the game *Game Serra Pelada*

(Sobrinho *et al.*, 2016) is focused on geometry. Also, many of the games are in a quiz format, such as the game *MathTimer* (Fernandes and Rebouças, 2016) and *Math Game* (Yildirim and Surer, 2021).

When comparing this study with related works, we consider the following points as its main contributions:

1. The game proposal *Dyscalc Game* was developed considering recommendations from the literature;
2. The game's proof of concept was refined through the execution of a co-design process;
3. The game was designed and developed considering regional and cultural aspects of the region and country, in the Brazilian Portuguese language, being specifically aimed at helping students with math learning difficulties;
4. This study also contributes by demonstrating, in a pilot study, the good performance of the game in relation to usability and user experience.

4.3. Limitations

This study has limitations inherent to any scientific research. The first one is that the number of participants in the co-design process could be greater, to allow the creation of more suggestions/requirements to be implemented. We believe it is important to carry out another round of co-design. The development process is continuous and, hence, new contributions will certainly allow *Dyscalc Game* to evolve. The second limitation is that *Dyscalc Game* was developed as a proof of concept to allow ideas to be validated. Therefore, it is not a complete game done to be put into production, so requiring additional levels, a full storyline, and a richer database with math challanges of different education levels (e.g., infant, elementary and secondary).

5. Final Remarks

This study presented the design and development process of digital learning object, a serious game called *Dyscalc Game*, to help the teaching and learning of students with math learning difficulties, including those with dyscalculia. The game was developed to be used by professionals, mathematics teachers in classrooms, pedagogues, psychopedagogues and psychologists. The game was implemented based on specific recommendations for game design for students with math learning difficulties and dyscalculics. For its development, there were also collaborations from a co-design process. A usability and user experience evaluation was carried out with *Dyscalc Game* with the participation of professionals and students. The results of the evaluations regarding game performance were positive for different UEQ aspects, and superior to many products on UEQ bechmark. Therefore, the game developed in this study demonstrated potential to be useful for both professionals and students.

Plans for future work include implementing a feature to allow professionals to insert new math challenges into the game. It is also intended to implement a feature to allow professionals to adjust the difficulty level of math challenges according to the player's level. Finally, we intend to extend the game to a full version in order to make it capable of being evaluated in long-term studies to verify whether it effectively improves students' academic performance.

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References

Association, A. P. **DSM-5: Manual diagnóstico e estatístico de transtornos mentais**. [S.l.]: Artmed Editora, 2014.

Avila, L. A. B.; Lara, I. C. M. d.; Lima, V. M. d. R. Intervenções psicopedagógicas e discalculia do desenvolvimento: uma revisão sistemática da literatura. **Revista Educação Especial**, v. 32, p. e80/ 1–21, set. 2019.

Bird, M. *et al.* A generative co-design framework for healthcare innovation: development and application of an end-user engagement framework. **Research Involvement and Engagement**, Springer Nature, v. 7, 2021.

Bland, J. M.; Altman, D. G. Statistics notes: Cronbach's alpha. **BMJ**, BMJ Publishing Group Ltd, v. 314, n. 7080, p. 572, 1997. ISSN 0959-8138.

Butterworth, B.; Varma, S.; Laurillard, D. Dyscalculia: from brain to education. **science**, American Association for the Advancement of Science, v. 332, n. 6033, p. 1049–1053, 2011.

Calderón-Garrido, D.; Ramos-Pardo, F. J.; Suárez-Guerrero, C. The use of mobile phones in classrooms: A systematic review. **International Journal of Emerging Technologies in Learning**, v. 17, n. 06, p. pp. 194–210, 2022.

Cezarotto, M. A. **Recomendações para design de jogos, enquanto intervenções motivadoras para crianças com discalculia do desenvolvimento**. Thesis (Master) — Universidade Federal do Paraná - Pós-Graduação em Design, Setor de Artes, Comunicação e Design, 2016.

Cezarotto, M. A. **Detailed game design recommendations to foster and sustain the motivation of children with dyscalculia in educational digital games**. Dissertation (PhD) — Universidade Federal do Paraná - Pós-Graduação em Design, Setor de Artes, Comunicação e Design, 2019.

Cezarotto, M. A.; Battaiola, A. L. Avaliação de jogabilidade em jogos para crianças com discalculia: Proposta de heurísticas. **Blucher Design Proceedings**, v. 3, n. 11, p. 30–41, 2017. ISSN 2318-6968.

Ekin, C. C.; Polat, E.; Hopcan, S. Drawing the big picture of games in education: A topic modeling-based review of past 55 years. **Computers & Education**, v. 194, p. 104700, 2023. ISSN 0360-1315.

Fernandes, M. de M.; Rebouças, A. Débora Dantas de S. Math timer: um objeto de aprendizagem para apoiar o ensino de matemática. **Revista Novas Tecnologias na Educação**, v. 14, n. 1, 2016.

Hinderks, A.; Schrepp, M.; Mayo, F. J. D.; Escalona, M. J.; Thomaschewski, J. Developing a ux kpi based on the user experience questionnaire. **Computer Standards & Interfaces**, Elsevier, v. 65, p. 38–44, 2019.

Hinderks, A.; Schrepp, M.; Thomaschewski, J. **User Experience Questionnaire**. 2023. Available on: ⟨https://www.ueq-online.org⟩.

Janssen, F.; Xavier, B.; Pereira, V. S.; Santos, R. dos. Investigando a elaboração de narrativas em jogos sérios. In: **Simpósio Brasileiro de Games e Entretenimento Digital (SBGames)**. [S.l.]: Sociedade Brasileira de Computação, 2019. v. 18, p. 1287–1295.

Košč, L. Developmental dyscalculia. **Journal of Learning Disabilities**, v. 7, n. 3, p. 164–177, 1974.

Masola, W.; Allevato, N. Dificuldades de aprendizagem matemática: algumas reflexões. **Educação Matemática Debate**, v. 3, n. 7, p. 52–67, 2019.

Monei, T.; Pedro, A. A systematic review of interventions for children presenting with dyscalculia in primary schools. **Educational Psychology in Practice**, Taylor & Francis, v. 33, n. 3, p. 277–293, 2017.

Santos, J. B. P. dos; Tolentino-Neto, L. C. B. de. O que os dados do saeb nos dizem sobre o desempenho dos estudantes em matemática? **Educação Matemática pesquisa**, v. 17, n. 2, 2015.

Santos, W.; Alves, L. D.o.m. - um jogo sobre funções quadráticas: Entre a educação e o entretenimento. **Revista Novas Tecnologias na Educação**, v. 14, n. 2, 2016.

Sobrinho, M. E.; Resplandes, D.; Valente, K. W. S.; Neto, E. S.; Filho, M. R. Game serra pelada: Projeto implementação e avaliação de um jogo educativo para o ensino de geometria para alunos do 9 do ensino fundamental. In: **Proceedings of Brazilian Symposium on Computer Games and Digital Entertainment 2016**. [S.l.: s.n.], 2016. p. 865–872.

Vacca, R. A. *et al.* Serious games in the new era of digital-health interventions: A narrative review of their therapeutic applications to manage neurobehavior in neurodevelopmental disorders. **Neuroscience & Biobehavioral Reviews**, v. 149, p. 105156, 2023. ISSN 0149-7634.

Yildirim, O.; Surer, E. Developing adaptive serious games for children with specific learning difficulties: A two-phase usability and technology acceptance study. **JMIR Serious Games**, JMIR Publications, v. 9, n. 2, p. e25997, 2021.