Game Design Recommendations Focusing on Children with Developmental Dyscalculia

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Abstract. Children with Developmental Dyscalculia's difficulties include those which affect the normal acquisition of arithmetic abilities. In order to improve their mathematic skills, these children are motived by the use of based-game interventions during neuropsychological rehabilitations. These games seek arithmetic training but present several game design constraints, which limit the real possibilities of use specially regarding motivational aspects. This paper presents a combination of studies on neuropsychology and game design to enhance user's motivation. In order to achieve such purpose, it comprises four steps: literature review, case study, data triangulation, and experts' evaluation. As a result, we offer a set of game design recommendations focused on user's motivation. This paper is a result of the first author's dissertation for the postgraduate program in Design.

Keywords: Game design · Motivation in games · Interventions for developmental dyscalculia

1 Introduction

Electronic games are considered a significant entertainment media able to captivate the user's attention, acting as an expressive mechanism to provide fun for players [1, 2]. Nowadays, modern society needs make the use of games not just an entertainment, extending this tool for serious contexts and activities to provide motivation. This is process of Gamification [3].

Neuropsychology has been using computer games during neuropsychological rehabilitation in order to motivate children with developmental dyscalculia [4–6]. Developmental dyscalculia is a specific learning disability which affects arithmetic abilities, meaning that children with this disorder have a severe and persistent difficulty on developing these skills [7, 8].

Several authors have presented positive results in using game-based interventions for remediating dyscalculia [4–6, 9, 10]. Despite the relevance of these authors' contributions to the design of arithmetic training, some problems remain to be solved regarding how can we develop games for this specific application. The lack of game design studies in general leads to non-systematized development of these game-based interventions. Constraints in game design limit the real possibilities of use for these games, particularly affecting the player's experience. This paper attempts to fill this gap

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in the development of games for children with developmental dyscalculia by relating neuropsychology and game design studies, aiming to define a set of recommendations focused on user's motivation. Thus, our research problem is "how to increase children's motivation using game-based interventions for dyscalculia?"

As a methodology, the research approach is exploratory and qualitative, comprising four procedures: literature review, case study, data triangulation, and expert's evaluation. In this paper, we present these procedures hierarchically, sequenced leading to the research results.

2 Literature Review

Through a narrative literature review, this phase established a conceptual framework based on accomplished studies on the specific area of this research. Moreover, we present information regarding game settings to increase user's motivation and highlight some dyscalculia characteristics. Hereinafter, we discuss the main results of this review.

2.1 Motivational Elements in Games

Regarding the game definition, this study adopt game as system in which players engage in an artificial conflict, defined by rules, resulting in quantifiable outcome [11]. In this case, system is a group of parts or elements forming a complex whole [11].

A review in game design studies implicitly or explicitly demonstrates that games are formed by elements, which are responsible for contributing or defining the player's experience [12]. Taking into account the idea that a game has forming elements, we have considered for this study seven elements for games [13].

- **Components:** They are the game objects that the player is able to manipulate physically or virtually in the course of game. For example, characters, ships, cards among others.
- **Rules set:** This element is responsible for defining the goals and procedures in the course of game. For example, scoring more points than the opponent, being first to achieve the goal, saving the princess etc.
- **Environment:** Game environment is the physical or virtual constraints of the game system. For example, board, levels, virtual worlds, etc.
- **Game mechanics:** This element describes the actions, which players can take in order to complete the game goals. For example, moving characters, maneuvering cars, throwing objects etc.
- **Theme:** The game theme is the subject matter, a fictional context or a metaphor used for contextualizing the rules set and the game system.
- **Graphical interface and information:** This category unifies two elements from the game system [13], interface and information, due to the interface element used for this study, which considers not just physical characteristics but also interface graphical aspects. Interface is the element used to allow the player to interact with informational game elements. Thus, information is the status of game shown to the player by the system (through the interface). For example, scores, visual instructions, etc.

- **Player(s):** This category represents the human factor in the game, the players and their behavior interacting with game system.

The preceding studies bring up an important perspective regarding the game system, highlighting that the game experience happens with the player interacting either with other players or with game elements [13, 14]. Thus, in order to enhance motivational and fun aspects in games, the most relevant part is how to establish and present the game elements to the player.

Game design publications referring to player's experience focused in intrinsic motivation usually adopt The Flow Theory [15]. Such theory refers to the player's mental state and best performance called "optimal experience", likely to occur when there is a balance between challenges and user skills leading to a deep sense of enjoyment [15]. Some studies expanded the Flow Theory to attend a specific application in game design [16, 17]. In this regard, there are eight recommendations to serve as guides on development of animations and games, aiming to increase learner's motivations [17]. We have adapted these recommendations to the context of this study, which we describe hereinafter.

- **Challenges:** Using challenges to promote user's motivation requires that the player's skills and challenge difficulty matches. When achieving goals, the amount of challenge must not exceed the player skills or underestimate the player's capacity.
- **Clear goals:** The goals in activity must to be as clear as possible to the player, clearly informing which goals the player must accomplish.
- **Performance Feedback:** It is the component which provides performance information to the player. Feedbacks are essential in games, for they sustain motivation once they provide the necessary information to keep the player up with the goals.
- **Emotional appeal:** It is customized information provided by means of narrative and characters in order to intensify the user's interest and motivation for the activity.
- **Cognitive process:** Metaphors and visual analogies work as a component to facilitate mental processing of information, assisting the player in understanding new contents with knowledge already processed by memory.
- **Sensory curiosity:** It means visual expression used for communicating information. Thus, in order to attract the user's attention, using graphical language can promote an aesthetic standard.
- **Control:** Offering to the user control and choice during the tasks or activities facilitates interaction and extends motivation for learning.
- **Immersion:** Flowing optimal experience offers some characteristics which promote engagement, interest and attention for an object. Such characteristics are full concentration in the activity, distractions exclusion from consciousness, and the distortion of time perception. This flow results from the preceding recommendations.

The foregoing discussion creates a framework of game information focused on improving player's experience. As a second part of literature review of this study, we present in the following pages some information related to developmental dyscalculia, and game-based interventions.

2.2 Developmental Dyscalculia

Developmental Dyscalculia is a disorder of mathematical abilities, not determined by intellectual difficulties or inadequate educational instruction [7, 8]. Dyscalculia presumably is a result of a specific impairment of brain function [7]. The prevalence of this disorder is around 3 to 6 % of the school-aged population [8, 18]. Diagnosing dyscalculia is a complex activity and a task for psychologists. All in all, in the diagnosis, standardized arithmetic assesses arithmetic skills in children [19]. These test shows if there is a significant discrepancy in the child's arithmetic achievement in relation to age, chronologic grade, and intelligence [18, 19].

Treatment for developmental dyscalculia should focus on educational interventions to enhance the assimilation of arithmetic concepts in particular [18]. In this sense, neuropsychological rehabilitation aims to increase children's learning using cognitive and behavioral techniques [20].

We have searched for information concerning neuropsychological interventions by means of a technical visit to the Developmental Neuropsychology Laboratory (DNL) at Federal University of Minas Gerais (Brazil). In DNL, a psychologist provides neuropsychological rehabilitation for children individually, using specific material with activities structured in seven modules, considering hierarchic arrangement of mathematics. Such modules are number sense; counting; transcoding; addition; subtraction, math problem solving; and multiplication. The laboratory credits the success of this rehabilitation treatment to three elementary concepts. They are

- **Motivation:** This concept is present in all rehabilitation activities. The purpose is keeping the child in a playful environment. Moreover, activity goals are configured in intermediate levels, focusing on the child cognitive profile, avoiding challenges which are too difficult or too easy.
- **Self-perception:** This concept provides the user some performance information. Thereby, graphical representations show the child their performances, highlighting his/her progress during the intervention activities, promoting a successful experience.
- **Errorless learning:** In this approach, rehabilitation activities prioritize the avoidance of errors during learning [21]. For this, the presented tasks have adequate levels for child's performance, reducing errors and offering more successful experiences.

Additionally, taking into account the aspects presented by DNL (UFMG), we summarize some instructional principles in literature, as relevant for using in neuropsychological interventions in order to increase the mathematical learning effectiveness [22, 23]. We filtered these principles considering those relevant for the present study:

- Individualized interventions are more effective [22].
- In interventions, repetition is necessary for learning, enhancing the learning process [22].
- A segmentation of the learning content is effective [22].

- Computer interventions allow children to practice and automatize math facts, also providing direct feedback. Therefore, in general, traditional intervention (with a teacher or psychologist) is more effective [23].

In rehabilitation treatments, neuropsychology publications have been studying the use of game-based interventions [4–6]. Game-based interventions are a positive tool for the neuropsychological rehabilitation, once it provides intense training on mathematical abilities in an entertaining environment. Additionally, they capitalize the attraction that children naturally have for computer games [6]. Nowadays, interventions use adaptive games in a large scale [4]. The development of these games aims to adapt task difficulties to individual abilities. Thus, software games are designed with an algorithm, which constantly evaluates player's actions in order to increase or decrease difficulty, maintaining an adequate difficulty [6].

After describing what the literature defines to enhance user's motivation in games, we present from now on the next phase, i.e. a case study with children diagnostic with dyscalculia.

3 Case Study

In the case study phase, two children aged 10 and 12 years old diagnosed with dyscalculia participated in a rehabilitation program conducted to evaluate motivation in games focused in this kind of learning disability. This rehabilitation program took place in the Developmental Neuropsychology Laboratory (DNL), located at Federal University of Minas Gerais in Belo Horizonte, Brazil. The DNL is a collaborator of this study, offering a significant support as well as their experience with diagnosis, interventions, and neuropsychological rehabilitation for developmental dyscalculia.

The small sample recruited is justifiable for three reasons: complexity to diagnose children with dyscalculia; necessity of a professional (psychologist) for each child during the rehabilitation; and the qualitative approach of the study. However, the study profited from the rehabilitation program longitudinal aspect along six weeks. We have used a codename to protect the identity of the research participants. They are group 1 (child 1 and psychologist 1) and group 2 (child 2 and psychologist 2).

This case study accomplished 12 rehabilitation sessions. From these, 6 sessions consisted in half an hour using games for each child once a week, assisted by the psychologist. After each game session, the children answered to structured interviews, aiming to obtain information related of the motivation and game experience among the weeks. Additionally, those psychologists responsible for conducting the rehabilitation program provided information using questionnaires regarding the children's behavior during the game interaction.

De Castro et al. developed both games used in case study [10]. They are *Shark*, and *Dance Dance and Dance!* (Fig. 1). Each child played each game three times. The used games are part of study sample and we selected them for this case study orientated by researchers of DNL. We have used as case study procedures a structured interview for children and a questionnaire for psychologists.

Fig. 1. Games used in case study (Source: De Castro et al. [10])

3.1 Case Study Results

We have analyzed the case study data in a qualitative approach, using the user's perspective to describe what was motivational or not in the games used during rehabilitation program.

Results for each child were distinct: for child 1, the games were motivational; on the other hand, child 2 considered the games not motivational. We infer that this heterogeneity occurred due to distinct children's profile concerning previous experiences with entertainment games. In this sense, child 1 is not an entertainment game user, contrary to child 2, who frequently use this type of game. Thus, there is a direct relation between user's motivation and their level of experience with games. Therefore, higher experience turns the user more critical of the game settings.

During game interaction, the children highlighted some elements that called their attentions. They were character, scenery, and rewards. However, the flow element "challenge" was the most responsible to increase or decrease user's motivation. This was evident when observing child 2's data. In both games, child 2 was motivated when starting the interaction, but along other sessions with the game, this motivation did not persist, tending to boredom. This occurred on game 1 (*Shark*), due to the task goals being too difficult for that child's skills. In contrast, game 2 (*Dance Dance and Dance!*) presented tasks goals which were too easy for that child. Accordingly, the game elements can be well set (e.g., characters, rewards), however if the balance between challenges and user's skills is not appropriate, the game will not be motivational. Additionally, for child 2, the excessive repetition was another aspect responsible for decreasing motivation.

Regarding improvements in the games, in order to enhance fun experience, the children have indicated some points, which are

- **The possibilities to manipulate character:** Taking into account that both games allowed limited action for the avatar, the children suggested extending these actions. For instance, actions can be extended in levels throughout the game, providing the player new possibilities of interaction and avoiding repetition.
- **Solving mystery in the game consisting of several challenges:** For the children, it is important a fictional context for the game, wherein challenges (game goals) are

present in a playful environment comprising different types of activity. This idea provides the player a not so evident cognitive training (e.g., addition calculations), once it is part of a narrative.

4 Establishing Recommendations

In this phase of the study, we provide an answer for the research problem based on previous information discussed. We established a set of game design recommendations for developing games for children with dyscalculia focused on user's motivation. As a methodology, we used data triangulation to intersect all study results in order to establish these recommendations (literature review + case study).

Moreover, in order to schematize the recommendations, we segmented our research problem into two secondary questions, which consider both neuropsychology and game design perspectives. As answers to these questions, we elaborated a set of preliminary recommendations structured in categories (Table 1).

Table 1. Establishing recommendations

Research problem	Secondary questions	Recommendations categories
How to increase children's motivation using game-based interventions for dyscalculia?	What should be considered in the conception of games from **Neuropsychology perspective?**	· Trained mathematical ability · Content structure · Activities
	What should be considered in the conception of games from **Game Design perspective?**	· Components · Rules set · Environment · Game mechanics · Theme · Graphical interface

After establishing these preliminary recommendations, experts evaluated a trial version, aiming to evaluate the recommendations' applicability on developing game-based interventions for children with dyscalculia. The evaluation consisted in a value judgment based on the experience of small set of evaluators. The experts were structured in two group composed by two game designers and two psychologists. Finally, in the last phase of this study, we examined the adjustments proposed by the experts. As a result, we offered the final version of the recommendation set, which we present hereinafter.

5 Set of Recommendations

This section presents a set of game design recommendations. These recommendations do not cover technical aspects of the development of games, focusing on the **pre-production,** considering game production cycle [24]. **Preproduction** is the first phase in a game production cycle, when producers define elementary game information as

concept, planning, main characteristics, limitations, and project requirements. Considering this, the following recommendations cover preproduction issues.

5.1 Neuropsychology

Trained Mathematical Ability

- **Use modules for training or teaching mathematical content based on a hierarchic arrangement.** Modules are number sense; counting; transcoding; addition; subtraction, math problem solving; and multiplication.

Content Structure

- **Structure the module's activities adaptively to child's (player's) cognitive profile.** An alternative is using an algorithm to analyze player's actions during the game, based on challenge intensity, adapting challenge intensity based on the performance of each individual player. Thus, there will be additional content when the player becoming proficient in the tasks.

Activities

- **Use repetitions in activities,** however too much repetition is unwelcome for user's motivation. Explore a fictional game context composed by levels, where repetition for learning is arranged as part of a narrative, not too evident to the player.
- **Single player games composed by individual tasks are more efficient.** However, it is possible to promote competitions using the player's own performances, stimulating him/her to seek even better results.
- **Use game-based interventions guided directly by a psychologist or teacher.** Use the game as part of a system, providing structured data about the user's performance in an interface for the rehabilitation administrator. This system can quantify the user's performance in several aspects, for example, activity, session, comparison with children the same age, among other relevant possibilities for neuropsychological rehabilitation.

5.2 Game Design

Components

- **Use character as a visual stimulus in order to attract the player's attention to the activity.** Allow the player to manipulate the character, additionally allowing a customization of their features. An alternative for this is providing new characters throughout the game with more possibilities of manipulation and customizations.

Rules Set

- **Provide the player instructions related to the game's goals, rules and possible actions.** An alternative is using animated tutorials, also offering an option "help" during the game for eventual doubts.

Environment

- **Use the scenery as part of a ludic game context, acting as a background for the game activities.** In this sense, by means of graphical expression, the scenery can promote an emotional appeal attracting user's attentions.

Game Mechanics

- **Promote automatizing arithmetic by game mechanics,** thus gradually stimulating the player to solve problems using the less time possible and with less errors. This automatizing must consider the individual child's ability.
- **Game mechanics must consider a balance between challenges and player's skills.** Provide challenges in an intermediate level for the player, not too difficult or too easy. This balance must consider player's performance, so the player may interpret those challenges as possible and motivational. An alternative is providing challenge tasks solution in levels or steps, gradually increasing difficulty.
- **Accomplish an initial placement test to locate players in different levels of game challenges based on individual player's skills.** This placement can occur in the own game system, using activities before starting to play.
- **Offer chances for the player "to survive" in the game activities.** This allows the player to recover from errors and not blocking their progress in the game.
- **Use errorless learning, avoiding negative feedback (punishment).** Change the negative feedback into an orientation (e.g. tips to be successful in the tasks), considering player's errors. The purpose is promoting the player's progress in the game activities instead of discouraging them with punishments.
- **Locate the game mechanics in a playful environment based on a narrative,** for example, solving a mystery (large challenge) in the game by means of several small challenges.

Theme

- **Use graphical elements based on a narrative, for example, character, scenery, mechanics, activities, rewards etc.** The narrative may use a metaphor or analogy as an alternative to improve the player's learning, and additionally form a graphical expression for the game.

Interface

- **Interface elements are part of the game's graphic expression**, which focused in player's motivation, being possible to use creativity in their design. In this sense, in order to design these elements, use consistency in typography, color, layout and arrangement. Moreover, avoid excesses, making visible only relevant information not to overload the player's mental processing.
- **Use graphical elements which allow player's navigation into the game system.** These elements allow the user to set elementary functions before playing.
- **Use graphical elements providing instructions to the player.** These elements present information about game components, set of rules, and game mechanics.

- **Use graphical elements providing immediate feedback and self-perception,** in order to show the players their performances during the intervention activities. For instance, scores, badges, leaderboard, missions, achievement, progress, levels etc.
- **Offer positive feedback to the player resulted from correct actions, in order to increase engagement.** Use different types of rewards, as intangible (digital on game system) and tangible (out of game system, such as small gifts). Systematically design these rewards to keep player in flow. In this sense, provide small or big rewards based on the difficulty of completed challenges.

6 Final Considerations

The set of game design recommendations established in this study is an alternative to enhance motivation for children with dyscalculia during the neuropsychological rehabilitation. This result contributes for orienting the design process of these games. Based on the study results, we highlight a need for systemizing the development of game-based interventions, contemplating the role of each game element for user's motivation. In this sense, we point out the necessity of considering user's perspective, knowing their needs and preferences for game settings.

Finally, we emphasize that our results are not final solutions. However, the recommendations provided in the current study are initial instructions, which may guide new studies, aiming to enhance the effectiveness of game-based interventions in neuropsychological practices. Moreover, the recommendations may increase the development of games focused in Brazilian children with dyscalculia, who nowadays lack games-based interventions.

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