Gaming in Dyscalculia: A Review on *disMAT*

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Abstract. Dyscalculia is a particular learning disability that affects around 6% of the world population. However, dyscalculics are not brainless; they fight to learn mathematics, notwithstanding nurturing an acceptable education environment at home and school. Indeed, dyscalculic children fall behind early in primary school, and may develop anxiety or a strong dislike of mathematics. When reach adult life are still paid less than ordinary people and have difficulties on handling their ordinary finances. Therefore, this work is about a game; *disMAT*, which is an app whose purpose entails to appeal children to train their mathematical skills. *disMAT* involves planning by choosing strategies for change as kids move through the game. Unlike a whole-class mathematics activity, a game may support one's child's individual needs. Undeniably, it must be challenging, have rules and structure, include a clear ending point, and focus on specific abilities.

Keywords: Dyscalculia · Gaming therapeutics · Learning disability

1 Introduction

Learning Disabilities (LD) interfere in the individual's daily life, in matter of social interaction, personal confidence and professional opportunities. Hopefully, nowadays it is possible to remediate some of these LD, or even attenuate its severity, which helps to increase their quality-of-life.

Development Dyscalculia (DD), or just *dyscalculia*, is a specific LD, belonging to the *Mathematical Learning Disabilities* (MLD) group. The DD's name is due to the fact that LD there exists since the conception of the individual. On the contrary, *acalculia* is what is called acquired dyscalculia due to a brain injury or other accident [1].

To a proper understanding of the concept (dyscalculia), it is wise to highlight its definition, i.e., dyscalculia is an "inability to perform mathematical operations", which can be seen "as development impairment in (…) mathematics". According to the *Diagnostic and Statistical Manual-IV* (DSM-IV), the screening criteria describes that the mathematical ability in the individuals is "substantially below that expected, given the person's chronological age, measured intelligence, and age-appropriate education",

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which "significantly interferes with academic achievement or activities of daily living that require mathematical ability" [2].

As noted in the various official definitions of dyscalculia, it may be subdivided in categories according to the type of affected fields or according to the brain's immaturity, which reflects on the severity of the disorder [3]. Regarding the type, dyscalculia may be understood as:

- *Lexical*, when one has difficulties in reading mathematical symbols;
- *Verbal*, when one finds it hard to name numbers, symbols or even quantities;
- *Graphical,* when one cannot write mathematical symbols;
- *Operational,* when one faces problems when carrying out mathematical operations and calculations;
- *Practognostic,* when one has troubles in enumerate, manipulate, compare and relate objects and figures of themselves; and
- *Ideagnostic,* when one finds it complicated to make mental calculations and operations, as well as understanding mathematical concepts.

It is relevant to note that an individual with lexical dyscalculia may have verbal dyscalculia and any other [4]; it depends on the degree of dyscalculia that he/she presents. Now, regarding this degree or severity, it may be distinguished according to three stages of immaturity [5]:

- A former one, when the individual with dyscalculia presents improvements after therapeutic interventions;
- An intermediate one, when the individual has dyscalculia along with other learning disabilities (e.g., dyslexia); and
- A last one, when the individual presents an intellectual deficit as consequence of a brain injury[1].

Classification, the process in which ideas and objects are recognized, differentiated and understood, in this case with respect to dyscalculia's types (indeed with respect to its severity), requiring multiple tests and exams, as well as experts from different fields (e.g., psychology, paediatric, education) to perform the assessment. In order to accomplish this goal, the screening of this disorder does not fit on a standard test, i.e., it involves a set of tests, namely psychological ones (e.g., dyslexia standard test and detection of warning signs by age range), and medical exams (e.g., EEG, FMRI, stress tests). Following the diagnosis or signs of dyscalculia, it is paramount to attenuate its consequences, namely due to the fact that dyscalculia stands for an irreversible disorder. Indeed, there are some therapeutics that may be applied to these cases, like re-educating the individual with brain training [6, 7]; using the LearningRX program, a piece of software that meets a variety of o cognitive needs [8]; adapting the teaching system (*Special Needs in Education*); or adopting didactic games [9]. But, to accomplish better results, it is wise to start therapeutics in the early ages of the children's lives [10]. Later, it will have impact on their adult lives and on the way it relates with every aspect regarding mathematical abilities.

[1] Acalculia can be included in this stage.

Those aspects are dealing with procedures, spatial and temporal memory, counting, calculations and numbers representation, either in a qualitative or quantitative form [11]. Some of these consequences may be seen as mistaken the left hand side with the right one; on the inability to represent objects in different forms (e.g., with numbers, dots, words); incapacity to point out the bigger figure given two of them; and others simple tasks that can disturb a regular daily routine. In terms of causes for this disorder there exist several approaches, viz [12, 13].

- Geneticists believe on a heritage base, especially when their parents present the same LD or genetic diseases (e.g., Turner's, Williams', and Fragile X syndromes);
- Linguistics suggest that there is a misapprehension of the language and its formalities, affecting the understanding of mathematics concepts;
- Neurologists think that the responsible areas for the number senses in the brain have malformations or are not entirely developed;
- Pedagogues interpret that DD is a consequence of an inefficient teaching-learning system;
- Paediatricians consider medical conditions as causes, like a poor intrauterine growth or exposition to harmful substances or high levels of lead during the pregnancy; and
- Psychologists state that environmental factors can contribute to DD, like a poor education or traumatic episodes. Unfortunately, DD is usually associated with others disorders as attention deficit, hyperactivity and dyslexia, which confuses the diagnosis and therapeutics.

Although DD has an incidence rate of 6 to 7%, its awareness is object of concern [14]. Additionally, the lack of innovative learning support systems to compete with the existent ones – computer software and outdated paper guides – constitutes the required motivation to develop a specific and didactic mobile application to individuals with dyscalculia [15, 16].

The next section is about the therapeutics gaming, in which it is presented the developed app, *disMAT*, along with its architecture, implementation and assessment procedures. A case study it is also available. In the last section are presented the conclusions and outlined future work.

2 Therapeutics Gaming

Since the therapeutics in these cases are recommended to start earlier as possible, namely in the primary and junior schools. At these levels, the children are between 5 and 10 years old, being at these ages that they develop the concept of number, i.e., differentiate between symbolic and non-symbolic representations of quantities. Therefore, the maturity of the conceptualization achieved in those years will affect their adult lives.

Moreover, different types of exercises, either mental, written or oral, must be designed and endorsed towards this purpose, i.e., helping the child to develop and improve it numeric sense [9]. Nevertheless, these drills have to be appealing to attract the child and well-planned, in order to work on the significant areas of the brain.

Therefore, and having into consideration the technological era through which one is going through, where children play with smartphones and tablets all the time and everywhere, the app creation came up as a mean to enforce therapeutics of dyscalculia and other math learning disabilities. Although the use of games as a mean to attract children to learn different math concepts is not a novelty in itself, the difference between the *now* and *before* appears in the type of games preferred by them. In past times children used to mount puzzles, play board games and even domino; now they prefer it in a digital appearance, as well as games with increasing difficulty, where they have to go through different levels of things that are not easily ended.

Hence, the opportunity to design a game directed to help children with dyscalculia emerged with the need to rise the mathematic results in the Portuguese system in particular, and on the globe in general.

3 *disMAT*

In today's technologic era, where gadgets are the trend, an electronic and mobile application is an attraction to the kids. Indeed, this app has the purpose to assist children with mathematical learning disabilities, and in particular with dyscalculia, in an attractive and fun way.

The developed application was named *disMAT*, in which *dis* comes from *discalculia* and *mat* from *mathematics* [1, 15]. It is an app whose purpose entails to appeal children to train their mathematical abilities in a three levels game, where the difficulty is distributed across a set of tasks (being used ten at each level) that intend to stimulate the brain's areas affected by dyscalculia. The last task it is not accounted to the final score once its complexity is mostly relative when considered in comparison or relation to the others tasks, i.e., it constitutes a bonus to children in terms of the way they see this challenge.

Additionally, it was created two languages versions, in English and Portuguese. Each screen view with written words has an associated button that reads all the content of that view, turning this app valuable for children who can read, who cannot read and who have difficulties in reading but want to test their knowledge in mathematic.

The last but not the least, it is important to refer that this app runs under the *Android Operating System* (AOS), since it is supposed to be the OS most common at the target population.

3.1 Architecture, Implementation and Assessment

The IDE Android Studio was chosen to develop this app, using languages as Java, C++ and XML, as well as other packages, like image edition and audio-visual ones to manipulate figures, and reading voice and associate it to the audio buttons. The final product consists of an *Android 4.2* app, with the vertical orientation set, the audio-visual buttons, free Internet access and no user restrictions.

As referred above, this app goes through nine plus one tasks approaching the areas of laterality, direction, size, memory, measures, time, orientation and quantities, and it

is organized by difficulty. This organization is depicted into activities[2] in Fig. 1, where it is offered the game's flow, i.e., subsequently to a preliminary page, it is presented a menu with the options *about, help* and *levels*. In *about* the player gets to the *app* purpose and who developed it; in *help* the user gets to know how to play with the game; and in *levels* the users changes to another view where he/she may consult the score attained at each level and the level where he/she may resume the game. Each level presents a task per view. After the last task, the user returns to the *levels* view.

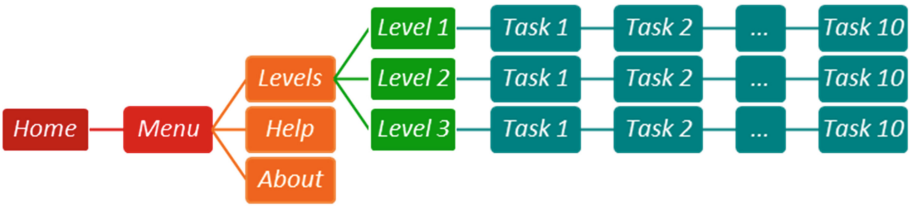

Fig. 1. The app's activities scheme.

To properly understand the usability of the app, it is presented in Fig. 2 the *disMAT* architecture diagram. As it may be observed, there are several users that play the app either in smartphones or in tablets. Once a user concludes a level, there is the possibility to send the displayed behaviour to a cloud (if connected to the internet) or to store the results in a database. Whenever the Internet access is on, the developer may access the session's results and handle them, i.e., to understand both the reasons for common misbehaviours and the actions that should be taken.

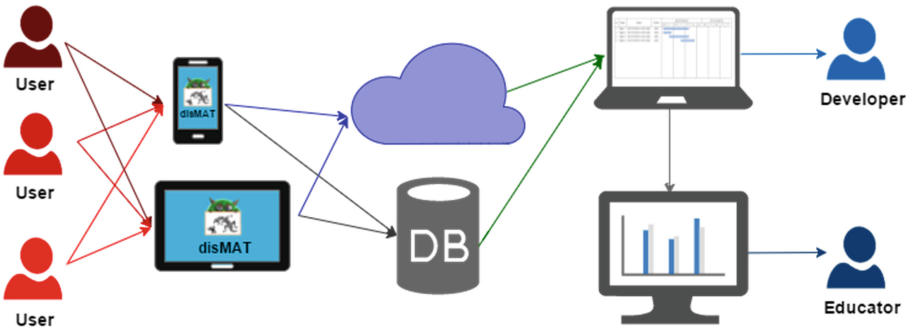

Fig. 2. The *disMAT* architecture.

After this pre-processing and analysis, the information is available for educators, i.e., it is an easy-to-use reference guide to help them define and correct student behaviours. Presented in an outline form, one may say:

[2] An activity is an application component that provides a screen with which users can interact in order to do something.

- Identifies the prime cause of every student conduct;
- Tells how each conduct affects teachers, other students, and the learning environment;
- Suggests methods for handling every student conduct;
- Reveals the common mistakes teachers often make when trying to correct conducts; and
- Cross references other related conducts.

The child assessment is made based on the score per task, the answer time in each task, the total task time, the score per level and the total level time. An overall analysis gives us the weaknesses and the strengths of the child, especially when the results can be compared with classmates. Additionally, the children answers a form where they identify their main obstacles, give their opinion on the app and suggest changes on it.

3.2 Case Study

This app was tested between two classes of the 3rd and 4th grades, with 19 and 26 students, respectively, where 47.83% of the population is female and 52.17% is male, with an age average of 9.18 years old.

In Table 1 are presented the main statistics about the two classes, 3rd and 4th grades, including the average age (already referred above), the gender relation (22 female to 23 male students) and the score's levels and times, in which it is highlighted:

- For Level 1 an average score of 89.56% and an average response's time of 01:36 min;
- For Level 2 an average score of 64.67% and an average of response's time of 02:14 min; and
- For Level 3 an average score of 72.44% and an average of response's time of 04:16 min.

Table 1. Comparison between *3rd* and *4th Grades*, and *Both Classes* by *Average Age*, *Gender Relation, Levels 1, 2* and *3 Average Scores* and *Response's Times*.

	Average Age (in years)	Gender Relation	Level 1 Average Score (in 100)	Level 1 Average Response's Time (min)	Level 2 Average Score (in 100)	Level 2 Average Response's Time (min)	Level 3 Average Score (in 100)	Level 3 Average Response's Time (min)
3rd Grade	8.68	7F/12M	83.68	01:42	63.68	02:09	70.00	04:29
4th Grade	9.54	15F/11M	93.85	01:31	65.38	02:19	74.23	04:06
Both Classes	9.18	22F/23M	89.56	01:36	64.67	02:14	72.44	04:16

In Table 2 are presented the difficulties experienced by the group in study, where is made a comparison between the two classes in terms of number of students and respective percentage, by field of difficulty. It should be noticed that there is an average of 18 students with difficulties, being the fields most affected the ones that deal with measures in terms of height (63.04%), telling the hours (82.61%), measures in terms of weight (60.87%) and positioning/orientation (58.70%).

Table 2. Comparison between *Field of Difficulties* in the *3rd* and *4th Grades*, and in *Both Classes* by *Number of Students* and *Percentage of Students.*

Field of Difficulties	No. Students			% Students		
	3rd Grade	4th Grade	Both Classes	3rd Grade	4th Grade	Both Classes
Size	5	3	8	26.32	11.54	17.39
Laterality	11	3	14	57.89	11.54	30.43
Memory (Pairs)	4	3	7	21.05	11.54	15.22
Measures (Height)	15	14	29	78.95	53.85	63.04
Time	18	20	38	94.74	76.92	82.61
Memory (Logo)	5	2	7	26.32	7.69	15.22
Measures (Weight)	17	11	28	89.47	42.31	60.87
Positioning/ Orientation	12	15	27	63.16	57.69	58.7
Money	14	8	22	73.68	30.77	47.83
Memory (Puzzle)	0	1	1	0	3.85	2.17
Average	10	8	18	53.16	30.77	39.35

Following these results, it is noted that dealing with measures, hours and orientation are the weak points of these students, maybe because the teaching-learning system is not appropriated or efficient, or because the tasks presented in the app were not clear enough to them. Otherwise, there is a need to make more tests and different types of assessments in both classes to detect the failure on the system to these children.

To conclude, each student of the group of 45 filled a form where 10 students answered that had difficulties, 15 answered that didn't know if had difficulties and 20 answered that didn't had difficulties. Of the 25 that had difficulties or where in doubt about it, 14 answered that had troubles understanding what were asked and 11 that had troubles understanding the game. In a general dyscalculia assessment per student, as presented in Table 3, it was observed that there are students that are between classifications limits, thus to inconclusive analysis, like the student number 4 that has a level of dyscalculia somewhere between high and very high severities.

Table 3. *Dyscalculia Assessment* per *Student.*

Student	1	2	3	4	5	…	41	42	43	44	45
Dyscalculia Assessment	Very High	High	Some	High/ Very High	High	…	High	Low/ Some	Some	Low	High

3.3 SWOT Analysis for *disMAT*

The SWOT (*Strengths, Weaknesses, Opportunities*, and *Threats*) analysis is a structured planning method that evaluates elements of a project or product. It involves specifying

the objective of the project and identifying the internal and external factors that are favourable and unfavourable to achieve that objective [17]. The core components of this analysis are:

- *Strengths*, i.e., features of the object under scrutiny that give it an advantage over and above others;
- *Weaknesses*, i.e., characteristics that place the object under study with a disadvantage relatively to others;
- *Opportunities*, i.e., elements that the object under analysis could exploit to its advantage; and
- *Threats*, i.e., elements in the environment that may cause trouble for the object under revision.

Indeed, the SWOT analysis provides the ground as well as the problem solving methodology in use with this app. The analysis is detailed in Table 4, being divided into quadrants that stand for beneficial and harmful influences of internal or external origin. One's reading may use the former quadrant for *Strengths*, the second one for *Weaknesse*s, the third for *Opportunities* and the later for *Threats*.

Table 4. SWOT analysis for the app *disMAT*.

	Helpful	Harmful
Internal origin	*Strengths*	*Weaknesses*
	Support tool for children with dyscalculia and others math LD Updated support tool to children trends and needs Possibility to extend and complete the app features anytime Big opening in the Portuguese market Suggest demonstrative results and information to the educator to a better scholar accompaniment	The need for internet access to send the player performance Modest design Few tasks and levels of difficulty Low fluidity of the views
External origin	*Opportunities*	*Threats*
	Embed an intelligent system where the tasks are selected automatically and presented according to the user's difficulties The search by the government for new technologies to implement in the education field The lack of learning support systems to screen and accompany the children with LD	The use of the tool in classrooms may be a problem if the educators do not accept it Arising of tools of this type since there are more and more companies investing in the mobile applications field

4 Conclusions

This math game may help not only to improve the math results obtained by children in their early years in school, but also to provide the elements that may potentiate their progress in this area, since they can play the game everywhere and at any time as long as they have a gadget with the app installed.

Indeed, *disMAT* came up in an era where the technologies are becoming the daily-basis of kids, reaching the individual's weaker areas without she/he notices it. But the

real requirement is projected in the need of a learning support tool to aid these kids to evolve outside classes, or even as a complement to them.

In an early conclusion, this tool has been well-accepted, and has been proving results in the route of distinguish evidences of dyscalculia, even though its low rate of accuracy.

The next step regards the development of an improved and wider app, serving tasks based on recent screening tests used by mathematicians and psychologists, without running away from the essence of the *disMAT*. The acceptance of this app by the educators and kids as a complementary tool should be worked on and achieved. Actually, the children who benefited most from the instruction were those who had the highest error rates at the beginning of the study. The results suggest that this improvement is in number sense access, rather than in number sense *per se*. On the other hand, and on the research side, it allows us to make inferences about which minimal factors are important in contributing to number sense development, i.e., in practice, it may offer individualized instruction on core cognitive components for children who are lagging behind. As such it may be a useful curricular supplement for educators and parents.

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