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Dyscalculia: What We Must Know about Students' Learning Disability in Mathematics?

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Abstract Dyscalculia is one of the less well-known learning problems in mathematics due to lack of exposure and study. Children with dyscalculia usually face arithmetic and symbolic number comparison issues, with about 3-6 percent of individuals affected. The lack of wide-ranging study and inconsistency in the condition's characterizations through studies have impeded progress in identifying the root causes of dyscalculia and how best to handle it. This problem can be more serious because it can prolong up to adulthood. Therefore, this paper will discuss the general aspects related to dyscalculia problems and their effects on children in their lives. This paper also explains the signs and symptoms that are needed to understand children who may have dyscalculia. Finally, this paper discusses what treatments or methods can be used significantly to help children improve their mastery and mathematical skills, including treatment for co-occurring issues. The implications are society should be aware of possible problems with their children related to dyscalculia and should always increase their initiative to use various methods to address the symptoms of dyscalculia, especially for children who also have other learning problems such as dyslexia and ADHD. Besides, increased knowledge of this distinction going forward, combined with longitudinal observational studies, provides tremendous potential to deepen our understanding of the condition and establish successful educational approaches.

Keywords Dyscalculia, Mathematics Disability, Specific Learning Disorder

1. Introduction

We often hear about various types of learning problems such as dyslexia, attention deficit hyperactive disorder (ADHD), and autism. Still, not many know that there are also learning problems that involve learning mathematics known as Dyscalculia [1]. [2] and [3] stressed the scarcity of learning disabilities studies in mathematics teaching and learning aspects. Besides, [4] suggested that more studies be conducted on learning disabilities in mathematics to gain a broader understanding of learning disabilities in mathematics. [5] stated that dyscalculia is a combination of the word 'dys' in Greek, which means difficulty and 'acalculia' which means calculation in Latin. Therefore, dyscalculia refers to the inability to learn mathematics. There are several commonly used terms related to dyscalculia. Some opinions refer to dyscalculia as a mathematics learning disability [6], and some refer to it as a type of mathematics learning disorder [7]. There are also those who refer to it as mathematical dyslexia or number dyslexia. However, this can cause confusion since dyslexia refers to the challenges faced in terms of reading, while dyscalculia relates to the challenges faced in mathematics. In addition, some indicate dyscalculia as developmental dyscalculia, but in fact, they all refer to thought to be a specific impairment of mathematics ability [8]. According to DSM-5 which is fifth edition update to

the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders, dyscalculia is now referred under the umbrella term of Specific Learning Disorder (SLD) with an impairment in Mathematics [9]. Dyscalculia is an alternate term used to refer to problems characterised by the processing of numerical knowledge, the acquisition of arithmetic facts and the performance of correct or smooth calculations. If dyscalculia is used to specify this particular pattern of mathematical difficulties, it is also important to specify any additional difficulties that may arise, such as difficulties with math reasoning or accuracy of the word reasoning [9]. [10] have suggested preliminary definition of dyscalculia into primary and secondary; *"Primary dyscalculia is a heterogeneous disorder resulting from individual deficits in numerical or arithmetic functioning at behavioural, cognitive/neuropsychological and neuronal levels. The term secondary dyscalculia should be used if numerical/arithmetic dysfunctions are entirely caused by non-numerical impairments (e.g., attention disorders)*".

In addition, the 'triple-code model' suggested by [11] is both neuropsychologically and anatomically based. The three elements are the expression of verbal, visual, and magnitude. According to this model, relatively simple arithmetic operations are conducted by the verbal system in the left hemisphere. In contrast, more complicated arithmetic procedures involving the calculation of magnitude and visual representations are bilaterally localized. This model is validated by experimental evidence from normal individuals doing arithmetic, as well as case reports from patients with focal brain lesions [11]. The number processing triple-code model predicts that three different representation systems may be recruited depending on the task: a quantity system (a nonverbal semantic representation of the size and distance relationships between numbers that can be category-specific), a verbal system (where numerals are interpreted lexically, phonologically, and syntactically, just like any other form of number) [11], [12].

Individuals with dyscalculia have difficulties understanding the number values, patterns and have a challenging time understanding and completing basic mathematical operations. They also have a hard time doing fundamental math problems and more abstract math [6]. Dyscalculia does not only affect children in school but also affects their daily lives. Moreover, a study conducted by [7] revealed the risks associated with psychosocial and economic problems occurring in England stem from the problems caused by poor mathematical ability. His study also found that 70-90% of the affected people completed their schooling at the age of 16 and the age of 30, found very few of them working full time. This indirectly contributes to a higher probability of unemployment and also causes depressive symptoms to be twice as high as people who do not have dyscalculia [8], [9]. The costs arising from the severe deterioration of mathematical ability in Great Britain have been estimated at £ 2.4 billion a year [8], [9]. Thus, the problem of dyscalculia needs to be explored more widely and addressed at an early stage, especially in childhood so that this problem will not be the cause for bigger problems.

2. Cause of Dyscalculia

In general, studies on the exact cause of dyscalculia are very few compared to studies conducted on dyslexia. [13] stated that the rate of study on dyslexia versus research on dyscalculia is 14: 1. This leads to a poor understanding of the real cause of this problem. So the obvious reason requires a more in-depth study to understand more deeply the real cause of dyscalculia. However, there are some findings of previous studies that can be used as a guide to determine whether an individual has dyscalculia. Although studies on dyscalculia are limited, it is estimated that approximately 5% to 7% of primary school children may have dyscalculia [7]. According to the DSM-IV, developmental dyscalculia is an unusual learning disorder with a frequency of 1% in the school-age population [14]. In another study, [15] have found that 3-7% of children, adolescents and adults have dyscalculia. This figure corresponds to some 84 000 to 195 750 primary-school pupils in Germany. However, unlike dyslexia, research on dyscalculia is still in its infancy [10]. Also, the study stated that this problem has the same rate to occur in both gender categories. Specifically, some studies have shown that this problem is more common among girls [16]. [10] suggested a developmental and integrative perspective to enable us to trace pathways of parallel and/or sequential mechanisms at varying processing levels (figure. 1). They argue that dyscalculia is a heterogeneous condition arising from individual developmental or functional variations at neuroanatomic, neuropsychological, behavioral, and interactional levels.

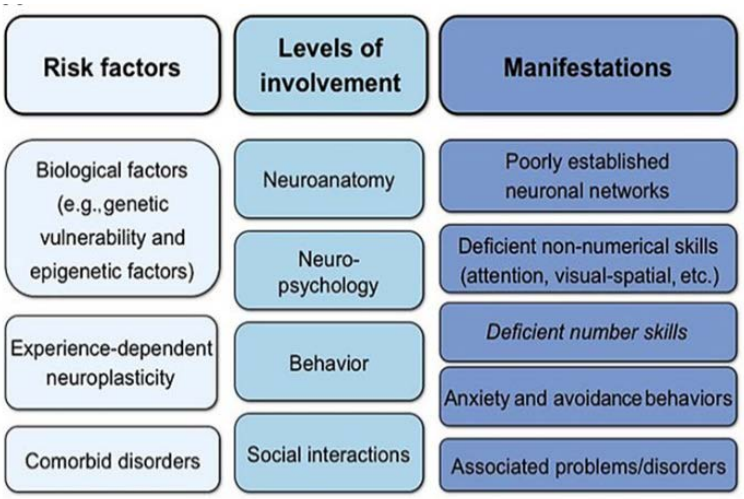

Figure 1. Development and Integrative Perspective on Dyscalculia by Kaufmann et al. (2013)

In general, not all dyscalculia-related problems stem from math learning problems. Other problems such as dyslexia, visual or auditory processing, ADHD and others can also affect children's abilities in mathematics, especially related to arithmetic. For example, the study by [15] found that a child with dyscalculia can also have problems related to other learning problems. It can be associated with ADHD and up to 60% of people who have ADHD also have a learning disorder, like dyscalculia [17]. Yet the opinion given by [8] stated that the real problem of dyscalculia (pure developmental dyscalculia) does not have apparent comorbidity with any other developmental disorders like ADHD and dyslexia. Their level of intelligence is normal, yet they have apparent weaknesses in the mathematical domain. Such prevalence figures indicate that a significant number of mentally innumerate individuals may be impaired by a particular learning disability, similar to dyslexia in the case of reading [13]. Consequently, from educators' point of view, these individuals may need personalized education techniques to improve their numeracy skills. Such treatments may only be personalized to individuals if the disorder's causes and effects are known. [13].

Various previous studies explain that dyscalculia can occur due to genetic factors [18]–[20]. However, studies [21] have shown evidence of children's genetic factors in two diagnoses of dyscalculia and dyslexia. They performed the research model concurrently, and found that genetic factors contribute to the comorbidity between reading and arithmetic difficulties. In a twin mathematical disorder study [19], 58 per cent of monozygotic co-twins and 39 per cent with dizygotic co-twins with dyscalculia probands also had dyscalculia. The concordance rates were .73 and .56, respectively and further supported genetic aetiology. Besides, [22] provide evidence of the role of genetic factors in the mathematical learning which are neurotransmitter system genes, genes involved in working memory differences and genes involved in synaptic plasticity (the coefficient of inheritance was 0.2–0.9). [22] also stated that according to the findings of the twin research, mathematical disabilities exist in monozygotic twins with a concordance of 70% and dizygotic twins with a concordance of 50%. In other studies, dyscalculia is partly due to a genetic aspect that is not yet understood at the molecular level, where it is emphasised that the coding variant (rs133885) of the myosin-18B gene has been shown to be correlated with mathematical abilities with a particular effect among children with dyslexia [23], [24]. Thus, based on the evidence presented, it shows that dyscalculia appears to run in families and genetics can also play a role affecting children's math deficiency.

Brain damage can also contribute to dyscalculia [15]. Previous research has shown evidence that results from the neurobiological system's deficiency for numerical processing (the total number of items in the set). This disorder causes difficulties in accessing arithmetic information during learning and development [13].

Today, dyscalculia is also associated with neuroscience theory which is now seen to dominate the study of developmental dyscalculia. Neuroscience theory assumes that dyscalculia is associated with the decreased magnitude representation (MR) which is often referred to as approximate number system [12] found in the intraparietal sulcus (IPS) located on the lateral surface of the parietal lobe. The IPS also helps you complete different numerical activities [11]. MR theory suggests that MR degradation will affect numerical skills that can lead to dyscalculia [8]. This theory explains that children with dyscalculia will have trouble in comparing non-symbolic number values. There are also other opinions about MR that concluded the MR itself as intact. Still, there is a disturbance in the relationship between the value of numbers and the number symbols. Also, there is a version that argues that the comparison of numerical values (non-symbolic numbers) is integral but there is a weakness in the comparison of symbolic numbers [25].

Study by [26] found that brain images taken using

functional magnetic resonance imaging (fMRI) while performing various mathematical activities displayed that children with dyscalculia do not use their IPS like their peers who do not have dyscalculia. The findings of this study indirectly indicate that dyscalculic brains did not work well with numbers which may cause problems in understanding number representation and simple arithmetic learning [27]. However, [27] asserted that in fact, children with dyscalculia do not have problems with their brain, instead their brain works differently.

In addition, [13] stated that dyscalculia may lie in disturbances of domain-general cognitive mechanisms such as working memory, visual-spatial processing, or attention. Working memory plays a significant role in encouraging mastery of arithmetic in adolescents, and both cases are closely linked to meetings where working memory is a cognitive component of promoting arithmetic skills [28], [29]. [25] suggested that individuals with both working memory disorders and math deficits may be best identified as suffering from secondary developmental dyscalculia. In the meantime, primary developmental dyscalculia which is the more severe condition, tends to be largely independent of working memory deficiency.

In addition, the visuospatial aspect may also be a common cause of dyscalculia due to the important role that visual-spatial plays on children's arithmetic development [8]. This is based on a study conducted by [30] who found that worse performance was shown in attention tests and visual-spatial processing in children with dyscalculia compared to the controlled variables. This is because children with dyscalculia are more prone to problems in understanding simple number concepts, lack of visual intuition for numerical symbols and problems in learning number facts and procedures. In addition, a poor visual observation also makes it difficult for children to complete or understand a new mathematical skill quickly. [31] stated that among the leading causes identified in the problem of dyscalculia is due to poor overall visual-spatial observation of a number situation in mathematics. This condition also causes the participants of this study not to be able to write numbers well and often have confusion with numbers.

Besides, genetic studies have shown that individuals with some of the essential genetic disorders, such as Foetal Alcohol Syndrome, Turner Syndrome or low birth weight, typically have severe impairments in the brain centres involved in numerical processing. These people primarily exhibit anomalies in the particular portions of the parietal lobes, which contribute to under-functioning of these regions.

3. Dyscalculia Signs and Symptoms

Studies on dyscalculia are not as extensive as other studies on learning disabilities [10], some systematic literature reviews conducted by previous researchers provide sufficient initial information to help the public understand the reviews of common characteristics of dyscalculia [13]. In general, dyscalculia is a learning disability in math. People with dyscalculia have trouble relating to the numbers that will represent the quantity. They may also have trouble recognising patterns, which is an essential part of understanding how to perform basic math operations [26]. [28] stated that a factor involving children with dyscalculia includes their weakness in the observation process as they do not observe the numbers in Mathematics as a whole. According to the code 315.1 (FBI .2) SLD with impairment in mathematics in the Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition, (DSM-5, American Psychiatric Association, 2013) dyscalculia is a particular learning disability, an impediment to mathematics, proof of difficulties with number sense, memorisation of arithmetic facts, accurate and fluent calculation and accurate math reasoning. Besides, [7] has stated some signs that needed to be observed in children related to dyscalculia. A young child with dyscalculia may:

- Have difficulties recognizing and remembering numbers
- Be slow in learning counting and losing track easily when counting
- Unable to associate number symbol with the number value
- Have difficulty identifying patterns and placing things in order
- Always need concrete or visual aids to help them calculate

[7] also said that as math becomes a significant part of learning in the school, kids with dyscalculia are likely to:

- Have difficulties in understanding and remembering basic mathematical operations such as addition, subtraction, multiplication and division.
- Can't understand the principles behind word problems and other non-numerical mathematical calculations.
- Have difficulties to estimate time.
- Struggle with math homework, tasks and exams.
- Have trouble sticking to the grade level in math·Hard to understand the learning involving visual-spatial like charts and graphs.

Dyscalculia also affects students outside of study time in the classroom where students will have difficulty remembering phone numbers, postcodes and even the scores for matches. Apart from that, they find things related to money to be complicated such as giving balance, calculating the amount of money and making an estimation of expenses. Also, children with dyscalculia find it difficult to estimate distance and determine the time required to move from one location to another. Other than that, it is difficult for them to remember the location, to state left and right and to read and state time.

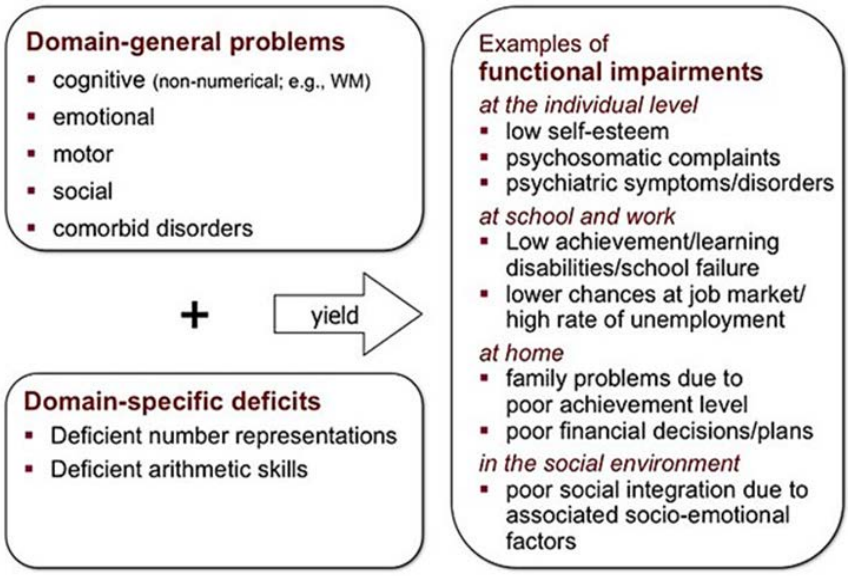

Figure 2. Schematic Representation of Potential Clinical Manifestations of dyscalculia.by Kaufmann et al. (2013)

In addition, [10] stated about the schematic representation of potential clinical manifestations of dyscalculia as shown in the study in Figure 2. They assert that there are two domains namely general problems domains which consist of cognitive, emotional, motor, social and comorbid disorders yielding with specific deficits domains namely deficit number representations and deficient arithmetic. These domains will eventually produce functional impairments at various levels.

4. Intervention of Dyscalculia

There are no drugs that can be used to treat dyscalculia [32] but there are various methods to overcome the problem of dyscalculia regardless of the stage. This problem needs to be resolved immediately to avoid worse scenarios that can disrupt a person's life, especially once they are adults [1].

One of the methods that need to be done is to give back specific interventions to a person with dyscalculia that is specific instructions related to the basics in mathematics such as making mathematical representations, making comparisons and reinforcing basic mathematical facts to students [18]. However, the lessons implemented should be more focused on helping students build a more substantial mastery of basic mathematics. Intervention in children with dyscalculia should focus on reconstructing basic mathematical concepts to strengthen and help them create a mental reflection on various mathematical elements especially related to basic facts in mathematics [33]. Teachers, including parents, should always stimulate students' understanding and memory by providing various stimuli using various representations comprising of manipulative materials to help students build knowledge relationships between numerical values and mathematical symbols [34]. Besides, teachers can also use materials that have a variety of colours to appeal to students' interest and attention to mathematics. The use of attractive colours is a good therapy to attract students and stimulate students' memory of mathematical concepts [35].

For children with dyscalculia, [36] found that teaching using multisensory instructions such as sight, hearing, touch and creative movement provides interesting and different.

methods for learning and understanding various concepts in mathematics. For example, using concrete objects such as using dice that allows students to see, touch and play with the objects can help give better understanding of the basic concepts of mathematics and help students build the relationship of thought between mathematical symbols and concrete materials seen [37]. There are various other methods through multisensory instructions that can be used such as visualizing with beads or cereals, drawing math problems, building with colored cubes and tiles, tapping out numbers, making musical connections, creating a hundreds chart, using pizza slices, putting movement into the mathematical concepts and building with base 10 blocks [38].

In addition, various technology-assisted materials can be used to help overcome the problem of dyscalculia among children such as graphing tools, math notation software and graphic organizers [39]. There are also applications that deal with simple number concepts. This technology-assisted materials can be used in schools as well as at home [40]. [13] in their research said that there were two adaptive computerized training tools which have been successfully built based on evidence from cognitive neuroscience to help overcome the problem of dyscalculia. The first is "the Number Race" to help improve the skills of mathematical representatives. In addition to providing input on the correct answer, the game asks children to

choose the greater of two sets and change the statistical gap between sets based on results, thereby making the challenge easier or harder.

The second program is called "Graphogame," which often plays a role, such as The Number Race, where people are expected to compare object sets. In comparison to The Number Race, which focuses on approximate estimation, Graphogame focuses on accurate numbers and tries to associate numeric symbols (Arabic digits). While both programs have defined cognitive processes as essential to the development of mathematical skills and both have resulted in improved numerical-comparison performance, neither program has generalized training effects of counting and arithmetic [12].

As already mentioned, one of the causes of dyscalculia is due to the existence of problems or weaknesses in the brain either inherited or the effects of injuries that have occurred causing difficulties for students to understand and remember mathematical concepts [18]. So there are alternatives that have been found to develop the function and synergy of the brain through the 'brain gym'. Brain gym includes basic gestures and exercises that are used to improve the understanding of brain stimulation by students from stimulation kinesiology [41]. Whole brain learning by motion repatterning and brain exercise training will enable students to access previously inaccessible areas of the brain. The use of Brain gym has been extensively studied in helping to improve students' ability in mathematics as well as helping in dealing with the probability of dyscalculia [42], [43]. Brain gym is described by [44] as part of Educational-Kinesiology. Educational Kineisology comes from the Greek word Latin, which is the science of human body movements. The core of Educational-Kinesiology, commonly abbreviated as Edu-K, was created by [44] to help students take advantage of all the latent natural learning potential through body movements and touch. Movement is one of the keys to the process of development and learning. The brain gym is a series of movements that will stimulate certain aspects of the brain and aid the right and left hemisphere [45]. This will optimize the use of all parts of the brain in the learning process or other activities as well as eliminate problems in learning [41]. Not only that, brain gym activities can also help improve children's mood and emotions so that they are more cheerful and positive in going through the learning process. So children with dyscalculia even those with other learning problems such as ADHD and dyslexia who find it difficult to focus and understand the teaching shown by the teacher, show hyperactive behavior, have poor communication, have short-term memory and obscure observations and thoughts can be treated with brain gym. However, Brain Gym is also based on neurological repatterning theories and more precisely, the Doman-Delacato theory of development [44]. This indicates that successful neurological functioning involves the learning of basic motor skills in the correct order [45] on the basis that ontogeny recapitulates phylogeny. Remedial activities are advised to repattern neural relations properly and thereby enhance academic success.

[41] stated that among the suggested brain gym movements are the types of ‘calf pump’ which play a role in attracting the muscles and nerves in the back of the spine so that children will be able to increase observation, attention and consequently help improve their concentration on something. In addition, another activity such as ‘gravity glider’ can play a role in helping to activate the brain for a sense of balance and coordination, improve the ability to organize and increase energy. Neck roll activity is also effective in helping children with dyscalculia to strengthen their visual and audio observation skills. Through neck roll activity, the rotation of the neck supports the relaxation of the neck and releases tension. When this movement is done before reading and writing, the ability of sight with both eyes and hearing with both ears will increase simultaneously. In addition, various other brain gym activities can be performed to help improve brain function, especially for children with dyscalculia problems such as 'cross crawl', 'brain button', 'hook up' and 'thinking cap'. These activities provide a platform to help develop and improve brain functions better.

To help children with dyscalculia in terms of information processing or information processing speed in understanding a new skill quickly, teachers need to always give enough time or 'wait time'. It will help children with dyscalculia to process information effectively, especially a newly learned mathematical concept [46]. [47] stated that by giving students more time to think helps children understand a mathematical concept better and helps them connect existing knowledge to build new knowledge. In addition, by training children through oral questions develops children's ability to think better. [48] stated that children who are frequently asked questions related to mathematics related to the correct method can help improve various intrinsic mathematical skills in themselves such as the skills to remember basic facts and the ability to perform mathematical procedures. In general, it helps improve children's sense of math. This is because oral questioning serves as a stimulus to children's thinking especially in the zone of proximal development where active interaction between parents or teachers through questioning activities that allows a faster understanding of mathematics can be achieved [49]. Although parents or teachers play a role as moderators in helping children with dyscalculia, the teaching should not be one-way but should be embroidered with oral questioning activities to help students' thinking and allow more interaction during activities.

In addition, the use of drill techniques is an important element although it is considered outdated and less suitable to be implemented in the current educational

trends [50]. However, for children with dyscalculia who often have trouble remembering basic facts and basic mathematical operating procedures, drill techniques are effective to help retain information in understanding in their long-term memory [51]. Regular drills provided can improve the information processing skills of children with dyscalculia and help them to retrieve stored information when needed. In addition, drill activities also help children to understand mathematical patterns, in turn, making it easier for them to make a mental picture of mathematical problem solving [52].

As is well known, there are many cases of children with dyscalculia but also have some other problems such as ADHD and dyslexia [15]. For children with ADHD, they find it difficult to concentrate, as well as impulsive and hyperactive. This will indirectly make it difficult to help children in understanding mathematics[20]. So an alternative needs to be find to overcome the problem first either by giving certain medications or supplements given by a certified prescriber or can also use non-medication treatment that is using behaviour therapy [18]. The purpose of behaviour therapy is to substitute healthy behaviors and habits of a child. The process is being led by the parents or teachers in order for them to focus on dealing with the dyscalculia problem later.

Study by [26] found that children with numerical and arithmetic problems are often associated with dyslexia. These problems stem from the existence of a relationship where children with dyslexia find it difficult to remember basic mathematical facts [15]. In fact, it's estimated that 43 to 65 percent of kids who have math issues also have reading issues. It also specified that by improving their reading skills, it will indirectly help in increasing their numerical skills, especially in problem-solving [1]. Not only that but helping to solve reading problems can also enhance the skills of dyscalculic children in understanding mathematical language for building stronger concepts [53]. However, in this context, parents cannot solve the problem of dyslexia and dyscalculia simultaneously because each problem has its own way of solving [54]. Consequently, the problem needs to be solved separately. Mathematical problems must be addressed with appropriate methods of mathematical instruction. At the same time, you have to deal with reading problems by using educational resources that are proven to support reluctant students [54].

5. Conclusion

Numerical and arithmetical deficits in learning-disabled children need to be given attention because not many parties are aware of these problems as well as the lack of knowledge and exposure to learning problems related to mathematics. Similar to dyslexia, most parents or teachers may have heard and learned about the problem and are more sensitive about it to their children or students. Therefore, all parties especially parents should always observe and assess their children's development in numerical and arithmetic aspects so that the initial problems regarding dyscalculia may be identified in advance and allow them to make appropriate interventions for the children immediately. This is important because if not addressed early, it potentially disrupts the emotional development of children as they may find that they do not have mathematical skills similar to their other peers and this can affect their schooling. In addition, in the future, it can also lead to psychosocial-related risks and economic problems caused by rampant unemployment. Therefore, parents need to play a role by always ensuring their children to find a way out of this problem by constantly monitoring their children's development. If it is found that their child may have early symptoms of dyslexia, then preventive measures should be taken immediately. Dyscalculia is not a disease but can be treated. During this process, early diagnosis and the use of effective pedagogical intervention strategies are important. Working collaboratively with experts, parents, and teachers can help to produce better outcomes. All Parties also need to constantly add knowledge and find ways to help children with dyscalculia since various alternative solutions can be used especially in dealing with this issue of dyscalculia.

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