The puzzle of dyscalculia

Authors:

Mieke van Groenestijn
Marie-José Bunck
Els Terlien

Abstract

The underlying paper was written in the frame of the collaborative project on dyscalculia of Denmark and The Netherlands. The Danish partners did a literature study into research about dyscalculia in Sweden, Norway, Denmark and the UK. For The Netherlands we chose three topics for discussion on dyscalculia that play an ongoing part in the Dutch education system.

The aim of this paper is to offer a brief overview of different scientific views on the concept of dyscalculia and what this means for working with students at risk in the classroom. It is not the intention to analyze the many studies that had been and still have been published on dyscalculia. It only highlights the puzzle, and maybe even a labyrinth, in which researches worldwide are still trying to come to a clear definition of dyscalculia as a learning disability opposed to mathematical difficulties. The many studies about the origin and aspects of dyscalculia are overwhelming, but teachers are supposed to get their students learning math.

Introduction

The concept of dyscalculia is still a subject for discussion in the Netherlands. In 2011 the national protocol ERWD (Van Groenestijn et al, 2011) was published for the support of students who experience severe mathematical difficulties or dyscalculia. The development of this protocol was commissioned by the Dutch Ministry of Culture and Education, in order to provide teachers with directions for students at risk, but in particular to prevent mathematical difficulties. This challenges teachers to come to early identification of possible mathematical difficulties and to adequate intervention. The focus in this paper is on three topics that influences the discussion on dyscalculia in The Netherlands:

1) The traditional view that dyscalculia is a specific learning disorder in individuals themselves opposed to severe mathematical difficulties.
2) New insights in neurosciences about the development of the brain offer new possibilities for learning and teaching mathematics.
3) Mathematical learning difficulties start in school when the teaching of mathematics does not match with the development of students at risk.

These three topics will be briefly elaborated in this paper. The focus is mainly on research and views that play a role in Dutch research and in the Dutch education system.

Differences between dyscalculia and severe mathematical difficulties

From the original view dyscalculia is assumed to be an incapability of a person to give meaning to numbers by which it is difficult to deal with mathematical facts and procedures. In The Netherlands it is assumed that about 2 or 3 percent of all students may have dyscalculia (Van Luit, 2006). In fact however, about 8 to 10 percent are having a dyscalculia statement. How is this possible?

Till to date it is still not yet clear what exactly the biological origin is that causes this learning incapability. Ruijssenaars, Van Luit and Lieshout (2004) state that the term dyscalculia is a descriptive term, just as dyslexia, that does not refer to a biological cause or explanation. It is a disability characterized by severe problems with learning mathematics, memorizing and recalling mathematical facts, rules and procedures.

Dyscalculia can be observed and diagnosed when students:

- show a discrepancy in development between mathematics and other subjects,
- are at least two years behind in mathematical development on standardized tests and to peers,
- are resistant for specific intervention
- don't have a below average intelligence (I.Q. $\geq$ 85)
- and the difficulties cannot be accounted to lack of good mathematics instruction.

When the result of a diagnostic interview shows a suspicion of dyscalculia, the student will receive a specific training during at least half a year. If the result of this training is low or nihil, the student may receive a statement of dyscalculia after a second diagnostic interview. The question, however, is in what way the student is diagnosed and what kind of specific training has been offered. Except for the criteria mentioned above, there are no specific rules in The Netherlands for diagnostic interviews and methods of specific mathematical training for dyscalculia. In general, an interview may consist of standard investigation into intelligence, working memory, motivation, comorbidity with dyslexia, ADHD, ASS or other, but may consist of different ways and materials for observing and analyzing the actual student's mathematical development. Such can be a speed test, a proficiency test, some tasks from the national standard test, tasks from textbooks and observations from teachers and parents, depending on the kind of difficulties and the age of the student (Van Luit, 2012). The result of this second part of the interview mainly depends on the expertise of the interviewer. This is also the case for the subsequent specific intervention. In many of these situations and in case of doubts, the student may receive a statement of dyscalculia, in particular because of the facilities for passing tests and exams: extra time and the use of a calculator. This may clarify the 8 to 10 percent of students diagnosed with dyscalculia.

According to DSM-V (APA, 2013), dyscalculia is a specific learning disorder that concerns persistent difficulties with mathematics and begins during school-age, although may not be recognized until adulthood. It concerns persistent difficulties understanding number concepts, remembering number facts or calculation procedures and difficulty with mathematical reasoning (e.g. applying math concepts or solving math problems). Early identification and intervention are particularly important. This definition describes symptoms and does not refer to a biological origin.

On the international level more descriptions and names are in use to define difficulties with the learning of mathematics. Mathematical disabilities, mathematical learning disabilities, mathematical disorder and dyscalculia can be seen as synonymous (Mazzocco, 2007). The terms *disability* and *disorder* refer to an incapability in the child itself, whereas *mathematical difficulties* are caused by environmental factors. "*A primary difference between both is that MLD is defined (in part) on the basis of its biologic origins. What remains unclear is the degree of overlap between both groups and the extent to which the groups differ on specific measurable characteristics*" (Mazzocco, 2007, p. 32). This may clarify why it is so difficult for practitioners to distinct both groups: the symptoms may look similar.

Dyscalculia in the frame of neurosciences

Research in neurosciences offers new insights about the development and working of the brain, by which it is possible to look at mathematical disabilities and difficulties with fresh eyes. What does this mean for dyscalculia?

Dehaene (1997) investigated the development of a mental number line in the parietal lobe of the brain. When this area shows underdevelopment, then it could be developmental dyscalculia. There could be an inability for making connections between observing and naming a quantity and recognizing or writing the number, namely the quantity of three objects (non-symbolic code), the word 'three' (verbal code) and the symbol '3' (symbolic visual code). Together known as the 'triple code'. Adequate mapping of these three codes is essential for the development of number sense and mathematics. Other researchers as Kucian and Von Aster (2005), Von Aster (2005) and Van Loosbroek (2006) support this theory, but indicate that more research into the number line theory is necessary to further build on this. Desoete (2015, 2017) examined that when children in kindergarten have problems with estimating quantities and number presentations, this could be an indication of dyscalculia. She also endorses the heritability of dyscalculia as shown in families and between twins.

According to Butterworth (1999) everybody is in principle 'born to count'. This means that everybody can count and develops a feeling for numbers. This is called 'numerosity'. Though, when some parts of the brain are underdeveloped or stay behind in development, difficulties may occur with learning mathematics. Then the person is 'born not to count'. This is what he names 'dyscalculia', but, as a neuroscientist he accepts the flexibility of the brain. Effective support and positive experiences with learning mathematics may help the person to overcome mathematical difficulties (virtuous circle). Insufficient or incorrect support and negative experiences with mathematics may lead to lack of self-confidence and math anxiety. This may increase mathematical difficulties (vicious circle).

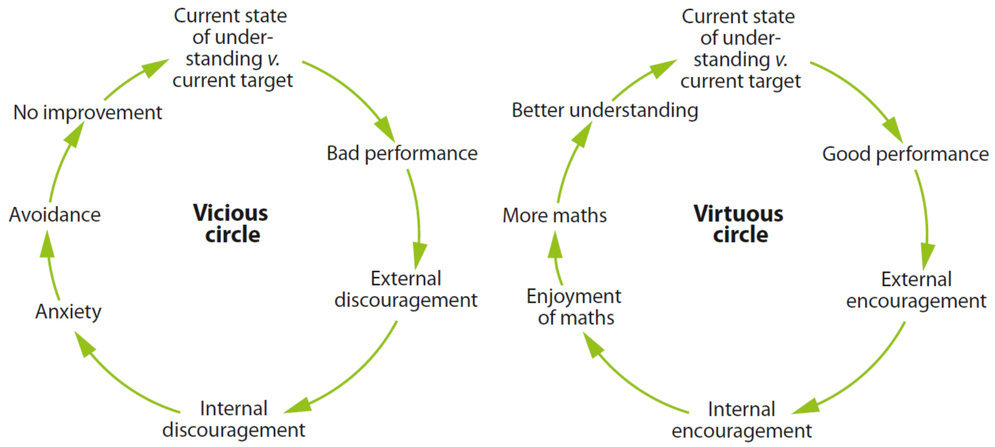

Figure 1. *The vicious and virtuous circle (Butterworth, 1999, pp 283-284)*

Geary (1993, 2004) studied the influences of differences between visuospatial, nonverbal numerical and verbal skills on the mathematical performance of MLD children, which led to three subtypes of MLD:

- a procedural subtype (left hemisphere): difficulties with acquiring mathematical concepts and procedures,
- a semantic subtype (left hemisphere): reduced accuracy and speed for arithmetic fact retrieval,
- and a visuospatial subtype (right hemisphere): difficulties in spatial representation of number.

Stock, Desoete & Roeyers (2007) added a fourth subtype, number knowledge, but this interferes with the visuospatial subtype of Geary. In practice it appears to be difficult to make a clear distinction between these subtypes because students often show a mix of the above mentioned phenomenons.

Another part of neuroscientific research into dyscalculia and mathematical difficulties focuses on the role of working memory and executive functions. Early research into these subjects came from Baddeley and Hitch (1974). Executive functions concern inhibition, shifting and updating. They direct actions of the individual person and affect the person's working memory. Inhibition is meant to stop distractive information during an action. Shifting concerns changing and combining different actions in complex operations. Updating takes place in complex operations that require temporarily storing information in one's working memory and recalling it later on when necessary. The central executive coordinates the different actions of planning, inhibition, switching attention and monitors processes. A fourth component, the episodic buffer is considered to regulate the integration of information from the working memory and the long-term memory (Baddeley, 2003). Inhibition, shifting and updating are crucial in complex (mathematical) tasks, e.g. comparing offers of rice in boxes with different weight, prices and percent off. Such complex tasks may cause overload of the working memory and by that mathematical difficulties. Kroesbergen, et al (2009) studied the role of executive functions and working memory in complex mathematical tasks with low achieving students. They concluded that enhancing executive functions may improve results in mathematics, but there is still insufficient information available for analyzing a possible relation with dyscalculia.

Huijsmans et al (2020) pose that subtypes of dyscalculia (see Geary et al, 2004) are conceptualized in the literature, but empirical evidence to support this theory is lacking. They examined whether profiles of mathematics performance can empirically be identified and whether the identified profiles also differ in underlying cognitive skills. They concluded that it is highly important to understand children's mathematics performance from an individual perspective, rather than by averaging these children over subgroups. They suggest that it is important to understand children's mathematics performance at the individual level, while considering individual differences in cognitive strengths and weaknesses associated with their mathematics performance. Such an approach is required to meet the (special) needs of all children in primary mathematics education.

Recent neurological research shows that the brain is flexible in its development (Jolles, et al, 2005, Jolles et all, 2008, Goshwami, 2007). Jolles compares the development of the brain to the infrastructure of traffic. There are highways, main ways and local ways. Young children use all kinds of local routes, but gradually they develop main ways and highways. The child develops concepts concerning quantity, mathematical language and symbols, but also in language areas, like, for example, the concept of 'animal'. The child first learns to distinguish a dog, cat, cow, chicken, fish, a duck, a bird, an elephant in local routes. Later on these animals can be categorized in main ways as, e.g. animals with two or four legs, birds can fly, fishes swimming in water, pets, wild animals, and finally as a highway distinction between animals and humans.

The concept of quantity starts by learning concepts as 'few, many, a lot', related to real objects and counting one, two, three. Later on these concepts can be used in a more abstract way by using the magnitude of numbers, such as three birds are just a few, ten birds are many, hundred birds are a lot.

Young children may even use the words thousand and a million to indicate that something is 'a lot', without actually knowing the magnitude of these numbers. On the highway level students learn that numbers can have different meanings. It is not only about quantity, numbers can also refer to age, time, temperature, a door or bus number or a phone number. They are able to directly understand the meaning of a number, depending on the context in which it is used.

Jolles (2008) describes the development of the brain as an ongoing process. It never stops. All parts of the brain work in collaboration and are flexible. If some part stays behind in development, other parts may take over. Development takes place in interaction with information offered from the environment as parents, peers and teachers, but also from media. The better the information, the better the brain will develop.

Neuroscientific research may offer interesting perspectives in the development of learning mathematics and by this, also on the concept of dyscalculia. Greenfield (2014) investigates the influence of digital media on the development of the brain. She compares the behavior of neurons with taxi drivers in London. Taxi drivers know where to go, but when streets or residential areas change, taxi drivers adjust their routes. Each driver chooses the best alternative ways he knows. Games that offer creating a digital living world are restricted to the digital possibilities. Neurons direct the brain, but moving in the digital world requires adaptation of the brain to the possibilities offered by the digital environment. Neurons will accept these restrictions and look for different possibilities in that environment. Neurons direct the brain but are flexible to adapt new ways of learning. Technology is continuously in development and may influence the cognitive behavior of people. Thereby, scientific research into learning and learning difficulties may lead to interesting new insights. Even the OECD (2002, 2007) is involved in this type of research.

Dyscalculia in the classroom

Symptoms of early mathematical difficulties come into being in the first years of compulsory school. Research of Geary et al (2017) and Desoete (2019) with children from preschool and kindergarten showed that first signals of possible upcoming MLD are already visible at the age of 3 to 4. This means that teachers must be aware of symptoms that could be an indication of a poor number concept. The teacher may observe difficulties with counting, determine and compare quantities. From grade 1 counting, memorizing simple addition, subtraction, learning time tables and reading time may give more indications for potential learning difficulties.

Depending on the teacher's expertise, school policy and possibilities, extra specific support may or may not be arranged. In The Netherlands teachers quite often wait for a few months or half a year, to see how the student develops and to wait for results on the half year standardized national test. In addition, there may be more students who need special support for e.g. reading and writing, ADHD, ASS or different problems. Many teachers in primary school have to teach mixed classes with students of different grades. Classroom situations may be rather complex, which challenges the teacher to observe several kinds of difficulties. Students with special needs on reading, writing and mathematics receive extra instruction in subgroups. More specific intervention on mathematical difficulties starts mostly in subsequent years.

In general it is not clear what type of intervention is offered. Of course, this may differ per student, but also per school. Quite often the first try exists of repeating parts of the mathematical content of grade 1 in the same way and with the same textbooks. If that doesn't work additional textbooks and hands-on materials have been used. If students fail to master the basic knowledge and core operations, they may fall further behind in the subsequent years.

The question is what kind of mathematics teaching is needed in case the instruction conform regular textbooks doesn't work. For example, how to improve the concept of number, or what to do when students keep using their fingers with counting? What to do if a student cannot memorize time tables? Most teachers teach from textbooks and many are not familiar with alternative ways of learning and teaching math. There are no directions what to do in such situations. Teachers do their very best in their own ways. In particular for young children textbooks may be quite abstract from the beginning of grade 1. Giving meaning to numbers in more informal playful ways when learning the basic facts and operations, time tables and core operations, is essential. Studies into different ways of teaching mathematics to children with mathematical difficulties or dyscalculia are necessary. The best way, however, is trying to prevent mathematics difficulties. As soon as a student shows difficulties with mathematics, math instruction should be adjusted. Such should already start from the beginning in grade 1, in particular when the student already shows difficulties with counting and number concept in kindergarten.

Teachers and school struggle with fine-tuning intervention for students at risk. They have restricted time and means for adjusting their teaching to every child with special needs. The longer this takes, the more a student may fall behind, demotivated and may develop resistance to mathematics. Finally students may get blocked. From that point teachers and parents may assume that it could be dyscalculia. If the student after that has been tested positive, then questions arises as: What is next? What kind of intervention is needed? Do we have possibilities to arrange this? Do we need a specialized teacher in private? What would be the costs? Can we afford this?

Diagnostic mathematical interview in school

The situation as described above requires more investigation in ways of learning mathematics and by that the ways in which students understand mathematics. When teachers don't succeed in adjusting their teaching to the actual need of students at risk, alternative effective ways of teaching must be available. This requires a detailed investigation in the actual mathematical development of the student and in ways students process information. Results of proficiency and standard tests may not be sufficient for directions about alternative ways of teaching. It also requires more knowledge about cognitive learning strategies, in particular for young children. The only way to adjust and fine-tune mathematics instruction to the actual development and need of students at risk, starts with a diagnostic interview that highlights the student's mathematical strengths and weaknesses, apart from a specific diagnostic interview on dyscalculia. The way in which such a diagnostic interview is organized should not only include levels of formal mathematical content but should also offer possibilities to students to show their best ways of understanding mathematical concepts and how they do mathematical operations. This may vary from informal playful ways and activities in real life situations to formal mathematical operations, depending on the student's age and years of schooling.

In that way, and as a follow up of the national Dutch protocol ERWD (Van Groenestijn et al, 2011), for special support of students with possible mathematical difficulties or dyscalculia, research started in the Netherlands in 2012 into the development of a diagnostic instrument that could respond to these demands. This instrument offers a detailed overview of all half-year levels in the mathematical domains, according to the (Dutch) mathematics curriculum, based on Action Theory. The students are questioned on four levels of actions: informal actions with the help of toys and real life hands-on materials, actions based on presentations of real life pictures, actions related to more abstract models like a number line and actions consisting of performing formal computations and memorized knowledge and procedures. The underlying theory of this study is Vygotsky's action theory, as elaborated by Van Oers (1987) and Van Groenestijn (2002) and applied in the protocol ERWD.

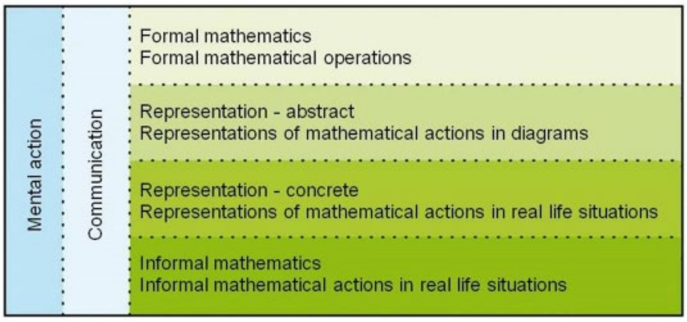

Figure 2. Representation of Action Theory (Van Groenestijn, 2002)

A first edition was elaborated for kindergarten up to grade 3 and was validated along the national standardized test Cito (Bunck, et al 2017). In 2016 the paper based version became digital as 'RD4', in Dutch '*Rekendiagnostiek op 4 handelingsniveaus'.* In English it means diagnostics of mathematical development on four levels of action, in short 'DM4'. In 2017 and 2018 the instrument was further elaborated up to grade 6. Validation research of the total RD4 instrument is running.

DM4 offers a detailed overview of all half-year levels in the mathematical domains, according to the (Dutch) mathematics curriculum. Questions for observation on four levels of action are described to direct the interviewer. Depending on the difficulties the student shows, a specialized teacher may do an adaptive diagnostic interview with the student and marks the results of the student's performance in a system based on the different levels of actions. The result of the interview is a profile that shows the student's actual development, strengths and weaknesses on mathematics. The profile offers detailed information for fine-tuning intervention. In most situations this offers a new start for the student to learn mathematics. In the event that the student still shows difficulties with mathematics, then an external interview on dyscalculia is advised. It is the intention that DM4 may replace the current system of different ways of doing mathematics interviews into dyscalculia and by this opens the way to a more unambiguous system of interviewing students with special needs for mathematics. In this way the subsequent intervention can also be better fine-tuned to the actual needs of the student. The quality of specific intervention can be better arranged and guaranteed. This may also lead to better possibilities for research into results of specific intervention to students at risk. More knowledge can be acquired about intervention to students at risks by which teachers for special needs can be better trained. The basic idea of DM4 is to build on the strengths and abilities of the student instead of their inabilities. If the subsequent intervention still doesn't work then a specific diagnostic interview into depth is required to find indications for possible dyscalculia.

Conclusion

Since features of dyscalculia become only visible from the beginning of school education, it is difficult for teachers in their classroom to identify students at risk in an early stage. A mismatch between teaching and the way in which students process mathematical information is coming up. The longer this mismatch is going on without efficient intervention, the more these students may fall behind, frustrated and finally blocked. The symptoms of mathematical difficulties may look similar to dyscalculia. In all situations, however, a fine-tuned intervention from the beginning of compulsory school is the only way to keep the student on track.

The dyscalculia puzzle has a long tradition and causes worldwide strong scientific discussions. It has been seen as a person's individual incapability to deal with numbers, but till to date it is not yet clear what exactly causes this disability. It is supposed to have a biological origin. 'Something' in the brain is not well organized and causes a disorder. Recent neuroscientific research as from Jolles (2008) and Greenfield (2014) into the flexibility of the brain, may open new ways for a different view on mathematical difficulties and dyscalculia.

It is remarkable that scientific research into dyscalculia mainly concerns the incapability of students to process mathematical information, but hardly into ways of teaching mathematics to students at risk and the ways in which students process mathematical information. Even when students are diagnosed with dyscalculia it is not clear what kind of special intervention is offered to these students by which in the end the student may or may not receive a statement for dyscalculia. There is little or no research into the results of intervention (Van Groenestijn, 2006).

In order to come to effective support of students with special mathematical needs, studies into mathematical difficulties and dyscalculia should start in the interaction between what and how mathematics is taught, into textbooks, mathematical activities in other subjects and the way in which students at risk respond to these activities. Research should examine the abilities of the students at risk instead of the inabilities.

Finally we may wonder what kind of mathematics students need for their future as adults in a technological society. Calculators, Excel and other smart software may replace time tables and paper based computation procedures. What will be the consequences for learning mathematics? We may wonder what kind of difficulties dyscalculia may include by then. The subject of mathematical difficulties and dyscalculia will still be an interesting topic for discussion in the near future. The dyscalculia puzzle has not yet been solved.

Authors (team RD4)

Mieke van Groenestijn,
em. Professor of Numeracy
Utrecht University of Applied Sciences

Marie-José Bunck
Senior Lecturer (retired)
Utrecht University of Applied Sciences

Els Terlien
Senior Lecturer (retired)
Utrecht University of Applied Sciences

Correspondence:
mieke.vangroenestijn@kpnmail.nl

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