Why is developmental dyscalculia/mathematical learning disabilities so difficult to define?

1. Research on DD is increasing, but remains limited compared to research on other learning disabilities, so the knowledge base on which current definitions are based is still emerging.

2. The term “developmental dyscalculia” (DD) does not refer to all forms of mathematics difficulty seen in childhood. Some children phenotypically show features of DD at some point of development, but their difficulties are not linked to a DD genotype; this is common among children with inadequate home or school learning environments linked to poverty.

3. DD is considered a mathematics disorder, and mathematics encompasses a very broad range of cognitive abilities, skills, and strategies influenced further by innate, environmental, cognitive, and social factors.

4. DD or some components of DD are likely to represent an extreme on a continuum of skills and abilities; therefore, it may be difficult to establish boundaries between typical development and DD, and knowledge of typical mathematics development and function can inform studies of DD. However, DD or some components of DD appear qualitatively distinct from other forms of low mathematics achievement, limiting the extent to which we can generalize findings from studies of typical mathematics development to the study of DD.

5. Existing research on DD has been fragmented. In view of the lack of universally accepted screening tools for DD or validated “core deficits” researchers develop and use a range of measures in their studies. These measures vary even when addressing the same construct (such as “counting” or “magnitude comparison”), even standardized test norms vary across countries. Studies replicating previous findings using the same measures, and especially analyzing intervention effectiveness using the same educational programs, have been rare exceptions.

6. Across research studies, educational media, and government reports, the terminology used when referring to DD is inconsistent. Math learning disability (MLD) has been used as synonymous with DD (as we do in this article), but also as distinct from DD when MLD is used to refer to the larger category of mathematics difficulties (MD). It is intentionally referring to all children who struggle with math. The emphasis on MD is understandable, given that all such children need our research and educational attention. However, not all these children have the severe, specific disability in math that we refer to herein as DD.
'Lack of research' problem: Research on DD is increasing, but remains limited compared to research on other learning disabilities, so the knowledge base on which current definitions are based is still emerging.

Table 1. Estimated prevalences of five specific learning difficulties. NIH research funding for these SLDs in 2000–2009 varied widely (1, 32)

<table>
<thead>
<tr>
<th>SLD</th>
<th>Estimated prevalence (%)</th>
<th>NIH research funding in U.S. $1000s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyslexia</td>
<td>4–8</td>
<td>27,283</td>
</tr>
<tr>
<td>Dyscalculia</td>
<td>3.5–6.5</td>
<td>1,574</td>
</tr>
<tr>
<td>Attention-deficit/hyperactivity disorder</td>
<td>3–6</td>
<td>532,800</td>
</tr>
<tr>
<td>Autism spectrum disorder</td>
<td>1</td>
<td>851,270</td>
</tr>
<tr>
<td>Specific language impairment</td>
<td>7</td>
<td>28,611</td>
</tr>
</tbody>
</table>

Problem of 'the Learning environment effect': The term “developmental dyscalculia” (DD) does not refer to all forms of mathematics difficulty seen in childhood. Some children phenotypically show features of DD at some point of development, but their difficulties are not linked to a DD genotype; this is common among children with inadequate home or school learning environments linked to poverty.

The complex nature of learning cultural skills: DD is considered a mathematics disorder, and mathematics encompasses a very broad range of cognitive abilities, skills, and strategies influenced further by innate, environmental, cognitive, and social factors.
Quantitative vs qualitative differences ('the cut score' problem):
DD or some components of DD are likely to represent an extreme on a continuum of skills and abilities; therefore, it may be difficult to establish boundaries between typical development and DD, and knowledge of typical mathematics development and function can inform studies of DD. However, DD or some components of DD appear qualitatively distinct from other forms of low mathematics achievement, limiting the extent to which we can generalize findings from studies of typical mathematics development to the study of DD.

‘Comparability and fragmentation’ problem: Existing research on DD has been fragmented. In view of the lack of universally accepted screening tools for DD or validated “core deficits”, researchers develop and use a range of measures in their studies. These measures vary even when addressing the same construct (such as “counting” or “magnitude comparison”), even standardized test norms vary across countries. Studies replicating previous findings using the same measures, and especially analyzing intervention effectiveness using the same educational programs, have been rare exceptions.
Even if we would use a very simplified definition of Dyscalculia as a severe difficulty in learning and performing basic arithmetic operations, we would still have a problem, how to assess and define the arithmetic skills.

Arithmetic is being able to count up to twenty without taking off your shoes.

Mickey Mouse (1928 - )
US cartoon entertainer

It’s getting worse with the arrival of computers as assessment and intervention tools:
"Research on CAI for numerical skills has been very fragmented. The replication of earlier studies using the same computer applications with similar or different kinds of subject groups are rare, making it very difficult to build cumulative evidence. The speed by which computer technology develops is one reason for this. Today, an intervention study, from planning to published results, usually takes longer than the life cycle of a computer or mobile phone operating system. Updates may have new features, which may no longer be compatible with the CAI task developed for the study. In other words, learning technologies tend to become outdated during a research project."


The 'Acronym' problem: Across research studies, educational media, and government reports, the terminology used when referring to DD is inconsistent. Math learning disability (MLD) has been used as synonymous with DD, but also as distinct from DD when MLD is used to refer to the larger category of mathematics difficulties (MD); it is intentionally referring to all children who struggle with math. The emphasis on MD is understandable, given that all such children need our research and educational attention.

So?

- After looking a series of longitudinal studies, we will come back to these problems.

EARLY STEPS -study

- A follow-up study of 1880 children from the beginning of the preschool, now followed to the 7th grade (data ready till the 4th grade)
- reading, math and cognitive skills
- + motivation, teacher-child interaction, home environment, attitudes, etc.

Number of articles found on psychInfo on MLD and variables of interest

Variables

- Vocabulary (Peabody Picture Vocabulary Test–Revised, PPVT–R, Form L; Dunn & Dunn, 1981)
- Phonemic Awareness (an initial phoneme identification task; see Lerkkanen, Poikkeus, & Ketokivi, 2006)
- Letter knowledge (Letter naming of all Finnish letters, upper case)
- Spatial visualization (W-J Spatial Relations test, Woodcock and Johnson, 1977)
- Counting Sequence skills (forward and backward counting accuracy)
- Arithmetic (BAT -Basic Arithmetic Test (Aunola & Räsänen, 2007): 3 minutes time-limited addition and subtraction tasks) measured at T3 = fall of first grade; T4 = spring of first grade; T5 = spring of second grade; T6 = spring of third grade
- controlled for Parental SES, gender

Statistics

- The parameters of the models were estimated using the full information maximum likelihood estimation with non-normality robust standard errors (MLR; Muthen & Muthen, 1998–2010).
- The goodness-of-fit of the estimated models was evaluated by five indicators: chi-square test, comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR).
- Growth-curve analyses were conducted
  - to estimate the level (i.e., intercept) and growth (i.e., slope) parameters of arithmetic competence and
  - to examine how these parameters were predicted by various linguistic and spatial precursors after accounting for demographic covariates.
- A significance level of .01 was used due to the large sample size.


The first model with n=1880

[Diagram of the model showing paths and intercepts]
The 2nd model (n=378).

Spatial skills and letter knowledge measured at kindergarten (6y) predict both level of math skills and speed of development till 3rd grade (mostly mediated by counting skills).

<table>
<thead>
<tr>
<th>Potential paths mediated by counting sequence knowledge</th>
<th>95% CI</th>
<th>Coef.</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial visualization</td>
<td>.05**</td>
<td>.035</td>
<td>.054</td>
<td>.144</td>
</tr>
<tr>
<td>Letter knowledge</td>
<td>.03**</td>
<td>.005</td>
<td>.054</td>
<td>.094</td>
</tr>
</tbody>
</table>

Note: N = 378. L. Arithmetic = the level factor of arithmetic competence; S. Arithmetic = the slope factor of arithmetic competence; Coef. = the standardized coefficient of the mediated indirect effect; Stand. = estimate of standardized indirect effect; *p < .05; **p < .01; n.s. = not significant.

Six reasons why it is hard to define MLD/DD.
Did we get any relief?

1. The ‘Lack of research’ problem
   - Yes. Longitudinal studies including a) multiple measures of numerical skills and b) areas of cognition less studied

2. The ‘Learning environment effect’ problem
   - Yes and no. We controlled for parental SES and studied effects measured before the formal education. But the formal education itself was a ‘Black Box’ in our studies.

3. The ‘Complex nature of learning cultural skills’ problem

4. The ‘cut score’ problem

5. ‘Comparability and fragmentation’ problem

6. The ‘Acronym’ problem
Six reasons why it is hard to define MLD/DD. Did we get any relief?

1. The ‘Lack of research’ problem
2. The ‘Learning environment effect’ problem
3. The ‘Complex nature of learning cultural skills’ problem
   • No. The studies were limited to the cognition–math, and math–math relationships.
4. The ‘cut score’ problem
5. ‘Comparability and fragmentation’ problem
6. The ‘Acronym’ problem

Six reasons why it is hard to define MLD/DD. Did we get any relief?

1. The ‘Lack of research’ problem
2. The ‘Learning environment effect’ problem
3. The ‘Complex nature of learning cultural skills’ problem
4. The ‘cut score’ problem
5. ‘Comparability and fragmentation’ problem
   • Yes and no. We have conducted a series of studies with different measures and at different ages trying to confirm earlier results. However, only some of our measures of mathematical skills were standardized tests, making it more difficult for others to replicate our studies.
6. The ‘Acronym’ problem

Six reasons why it is hard to define MLD/DD. Did we get any relief?

1. The ‘Lack of research’ problem
2. The ‘Learning environment effect’ problem
3. The ‘Complex nature of learning cultural skills’ problem
4. The ‘cut score’ problem
5. ‘Comparability and fragmentation’ problem
6. The ‘Acronym’ problem
   • Yes. We studied the differences between those with LA to those with MLD trying to find out, whether there are specific differences between LA vs. MLD (Problem 4: quantitative vs. qualitative), and thus, that the naming matters in definitions.
Did we learn something worth remembering?

1. Learning the symbolic systems (letters, numbers) is a predictor of numerical skills
   - how do we learn symbolic systems? Symbol-naming, symbol-meaning relationships

2. Spatial thinking seems to be an important factor in numerical development and also in differentiating children with LA and MLD
   - but what are these spatial skills…

R&D project (2014–2017) on visuospatial perceptual disorders

- Computer-assisted assessment and intervention on visuospatial perceptual skills including visual math
- Web knowledge-base on visuospatial perceptual skills and disorders to teachers, therapists, parents, and those concerned

Thank you!
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