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Mathematical Difficulties in Singapore: A Case Study Approach

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Introduction

The assessment and identification of children with learning difficulties in mathematics in Singapore has not been much researched and discussed in journal articles. The majority of studies in the international literature are based on case studies, which is the approach adopted here with 10 cases in the Singaporean context.

Case study cannot hope to confirm or disconfirm any new causal theories (Robson 1993), but it can contribute to an earlier stage of scientific enquiry, of collecting and classifying relevant examples, and so illustrate directly what difficulties children and their parents and teachers are facing. It may through analysis throw some fresh light on assessment, differential diagnosis, curriculum and intervention effects and thus contribute to a broad understanding of learning difficulties in maths and how children might be helped to learn.

The Background:

Learning difficulties in mathematics are sometimes called Mathematical Learning Disabilities (MLD), or just MD, and sometimes developmental dyscalculia, or simply dyscalculia. The former is preferred in the USA, while the latter is more common in the UK, where the government defines it as "..a condition that affects the ability to acquire arithmetic skills. Dyscalculic learners may have difficulty understanding simple number concepts, lack an intuitive grasp of numbers, and have problems learning number facts and procedures. Even if they produce a correct answer or use a correct method, they may do so mechanically and without confidence." (DES, 2001) In the USA, MD falls under the Specific Learning Disabilities" umbrella. DSM-IV (American Psychiatric Association, 1994) defines it with the following diagnostic criteria:

a. Mathematical ability, as measured by individually administered

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standardised tests, is substantially below that expected given the person's chronological age, measured intelligence and age-appropriate education.

b. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living that require mathematical ability.

c. If a sensory deficit is present, the difficulties in mathematical ability are in excess of those usually associated with it.

The concept of dyscalculia is quite controversial, with claims that this neurological condition is found in only around 2% of the population, and that the remainder reflect learning difficulties in maths (Peard, 2010). In Singapore, however, it is most common to use the term "dyscalculia", but the assessment and identification of children with MD is relatively uncommon, and there are no government guidelines on terminology or criteria for assessment other than where difficulties "in mental calculation" (MOE, 2011) co-occur with dyslexia, at present.

On the other hand, Singapore is renowned for the success it has achieved in mathematics education, especially with its top ranking in the third TIMSS study (Kaur, 2009). There is a considerable body of literature on mathematical education in Singapore (see Mathematics Education: The Singapore Journey, 2009), which includes concerns with difficulties in learning many aspects of maths, and with some particular difficulties (notably maths and test anxiety). However, this literature does not mention dyscalculia and refers only very briefly to remedial and special education for children with MD. This disjunction between mathematics educators (e.g. Royer, 2003) and learning disability and special education researchers (e.g. Hulme & Snowling, 2009, Pennington, 2009, Chinn, 2012) may in fact be international. There are few references in the books and articles of either group to the other.

Singapore provides an important crossroads where maths education and a concern to help children who have difficulty meet. Singapore is now one of the most prosperous and developed countries on Earth, and it sets high standards and has high aspirations for its young people's education. It prides itself on being rigorously meritocratic, and selects schools and streams within them through a national exam at 12 (Primary School Leaving Examination, PSLE) testing English, Maths, Science and Mother-Tongue. Parents provide very high levels of support to children, and most students attend some additional tuition beside their regular schooling. At the same time awareness of the nature of learning difficulties is growing, especially in literacy. English is one the country's official languages and education is almost entirely provided in English. Singapore has one of the largest Dyslexia Associations in the world (DAS, see www.das.org.sg), and awareness of the nature and value of skilled identification and support for children with literacy difficulties has grown steadily. Tuition in maths has always been sought by parents and awareness of the need to consider dyscalculia or MD alongside dyslexia is now beginning to grow. Singapore DAS has begun to offer maths tuition in addition to literacy.

Two new books by well established teacher-researchers have provided excellent materials and guidance for the assessment of children with MD in the UK: Chinn has written much on mathematical learning difficulties and dyslexia (Chinn and Ashcroft, 1993); his new book "More Trouble with Maths' (2012) provides detailed materials and guidance on assessment, and Emerson and Babtie have produced a similar book, "The Dyscalculia Assessment" (2010).

Chinn mainly talks about "maths difficulties" rather than "dyscalculia'. He believes a range of standard cognitive assessment tools, including WISC-IV, are helpful in understanding the difficulties of individual children. He has developed several specific maths assessment tools to clarify children's' strengths and difficulties in maths learning and performance. These include the 15 Minute Test, a general calculation skills test, brief timed tests of addition, subtraction, multiplication and division skills, an Anxiety test to explore children feelings about maths and the maths lesson, and a brief word-problems test. He also provides extensive guidance on informal observation work with children whose mathematical learning presents concerns. Emerson and Babtie also offer a broad framework for assessment, with more detailed and systematic observation and curriculum led assessment, without standardised testing.

There is some firm evidence of co-morbidities between MD and other learning disorders, based on a shared genetic underpin for maths and reading of 0.74 (van Daal, van der Leij and Ader, 2013). There are indications that more children may have both MD and dyslexia than dyslexia alone (UK, Lewis Hitch and Walker,1994), and maths difficulties are typical in some syndromes (Turner's, Fragile X, Pennington, 2009). In general, associations with other disorders such as ADHD and Specific Language Impairment (SLI) cannot straightforwardly be predicted. This appears to imply that when an explanation of a children's mathematical and other difficulties are being sought, multiple diagnoses should be the default.

Maths in Singapore is different from other countries especially because of the emphasis at the primary stage on solving word problems; a high proportion of PSLE maths involves these problems. They involve both very careful reading and understanding of the questions (which are often multi-step), and the use of a specific "bar modelling" technique for solving them, leaving algebraic approaches to the first secondary year. So Singapore children have arguably to be able to analyse logically complex statements and represent them in pictorial form in order to solve these problems. A particularly striking example from a Primary 5 paper (children aged 10-11) was:

> *"Bin has $30 more than Ron. Wei has 4/3 of the average of what Ron and Bin have. The average amount of money that Bin and Wei have is 1½ of Ron's money. How much money does Wei have?"*

The importance of word problems of this type means that assessment has to include work on Singapore maths. UK or US problems are not generally in the same league.

In literacy, the importance of rigorously researched "interventions" (that is, additional teaching or support that supplements mainstream class teaching) has been strongly advocated, especially in the USA (eg Torgeson, 2001) but equally in the UK (Hulme, 2011). Interventions, in this sense, are not much yet available in the MD literature. Much of the mathematics education literature is about teaching approaches, but this is nearly always mainstream class-teaching. Some general principles for helping students have been suggested by Chinn and others (eg Miles & Miles, 1992): use of concrete materials, teaching to particular learning styles ("inchworms vs grasshoppers"), making verbally explicit statements about mathematical processes and supporting calculation inefficiency with various aids, but their approaches have not been tested experimentally. Interventions for MD in Singapore must necessarily be speculative at this stage, it seems.

It is widely agreed that causal explanations for MD/dyscalculia are not yet available, but there appear to be two main positions: that there may be a single ultimate cause (eg Butterworth, 1999, numerosity) or that there may be a range of separable difficulties (including numerosity, verbal reasoning, working memory, long-term memory, spatial ability). Hulme and Snowling (2009) suggest that a single cause may apply to "pure" dyscalculia while multiple causes may affect children with co-morbid dyslexia and dyscalculia. Geary suggests three subtypes, a procedural type who have difficulty learning arithmetical strategies linked to verbal memory weakness, a semantic memory type with difficulties retrieving facts from long-term memory and a visuo-spatial subtype, who have difficulty representing number spatially (Geary, 2004). This lack of consensus about causality has implications for psycho-educational assessment.

Very few studies of dycalculia or maths difficulties in Asia have been published. In 2002, Ramma and Gowramma report an extensive study suggesting how children might be identified within Indian Primary schools; they found around 5.5 to 6% of children were dyscalculic. More recently, Chan and Tang (2013) examined differences between students with dyscalculia and those who were not dyscalculic but who had "low numeracy", using two different scores from the Butterworth "Dyscalculia Screener as the basis for the distinction. They used a series of tasks exploring the differences between symbolic and non-symbolic tasks with their Grade 1 children in Hong Kong, and suggested that the Butterworth dyscalculics were satisfactory at symbolic tasks, but not non-symbolic tasks, while the non-dyscalculics showed the opposite pattern.

In the absence of agreement about labels, clearly established diagnostic criteria, assessment techniques, information about associations with a wider range of specific difficulties, interventions, causal explanations and evidence about the Singapore context, this background analysis suggested that a case study approach (Butler et al, 2005, Peard, 2010) in Singapore would be informative as far as these issues are concerned.

Research Aims

The aims were to consider what are the most helpful components of an assessment of maths difficulties, what diagnostic criteria and labels might be appropriate, and how co-occurring conditions might affect diagnosis; what effects the Singapore context might have, what interventions and accommodations might be most relevant, and what models of the causes of maths difficulties might best guide assessment.

Methodology

This study examines the findings of a series of psycho-educational assessments of children to shed some light on the research questions. By its nature a case-study does not attempt to prove particular causal explanations of MD. It aims instead to suggest which factors may be most worth further investigation, and to sketch the landscape beneath the terminological and procedural jungle of assessment and labelling.

Data are presented from two series of cases involving MD:

1. Singaporean children assessed because of primary concern about mathematical learning difficulties or dyscalculia;
2. Children from International Schools either in Singapore or in the SE Asia region about whose mathematical learning there was concern alongside concern about literacy or general learning difficulties.

The main focus of this paper is the first group, but the second group provide some additional contrasts and raise some further questions beyond the scope of the main series.

The first series is grouped by age, because the stages of education in Singapore seem to bring particular challenges, hence different kinds of referral seem to be presented at different ages.

The children were not seen for research purposes, but to provide an assessment report at their parents' request, prior to further decisions about additional tuition, other help or exam accommodations. The first series includes all children seen because of MD, while the second includes all children seen following more general concerns where MD seemed a significant issue. The children were all seen between October 2011 and July 2012 at the Dyslexia Association of Singapore (DAS).

DAS's main role is to provide assessment and regular tuition in small classes for Singaporean children with dyslexia. A small team of specialist psychologists assesses children for dyslexia and write reports which include a diagnosis and recommendations for teaching including additional tuition, most often via DAS classes. Children are not specifically assessed for other developmental disabilities by this team, although they may suggest that further assessment for other difficulties such as MD is advisable. Since August 2011, DAS has also offered an assessment and tuition service to the nearly 2 million expatriates living in Singapore and to the large numbers living in the region. A new International team was formed including two experienced educational psychologists from the UK, a senior Speech and Language Therapist and recently an Occupational Therapist, together with a team of qualified teachers and experienced tutors. The author was part of the International team and as it happened was the only psychologist wanting to offer assessments of mathematical difficulties. Thus the cases reported were from referrals from Singaporean parents wanting an initial assessment only of MD, or where there had been previous assessment which did not focus on MD, or from expatriate parents living in Singapore or the SE Asia region wanting a general assessment including a significant maths concern.

DAS began to offer classes for maths as well as literacy difficulties in 2011 and demand has increased rapidly. Further psychology assessment is not required to access the weekly maths classes; parental request is sufficient, so the first series presented here did not carry with them issues and concerns about entry criteria for classes as such. However, the Singapore Ministry of Education expects children entering DAS literacy classes to have a dyslexia diagnosis and so there is background expectation that assessment at DAS may lead to a diagnostic label. Usually parents request a "dyscalculia assessment" rather than an investigation of mathematical learning difficulties, probably because of this expectation. In discussion about their referrals, parents were told that a dyscalculia diagnosis was a possible outcome but this should not be expected; the main purpose was to investigate possible mathematical learning difficulties (MD).

Details of all assessments have been anonymized and parental agreement to present the data in this way has been obtained.

The Cases:

1. Young children with possible MD:

Two children ages 6½ to 7½ in Primary 1 provide interesting similarities and contrasts. Andrew had been assessed already by an experienced and qualified psychologist and this assessment had found he was of about average general ability, articulate but with some weaknesses in reading comprehension, with an attention difficulty severe enough to be described as ADHD. He was attending Kumon classes but had made no progress on double-digit subtraction for some weeks, and his parents were getting worried. Ben had also been seen by a psychologist, and had at first seemed autistic, but this impression had altered and he was also now seen as having a mild attention difficulty. He seemed badly stuck on dealing with numbers above 9, in spite of a real facility in using a Chinese abacus.

Key background ability data is detailed in table 1.

These boys were thus quite similar in background abilities: Ben had a significant previously diagnosed language difficulty (which was assessed as more severe on CELF-IV), both were quick and somewhat impulsive, and both had satisfactory word reading, thus ruling out the possibility that they couldn't read the questions in maths. Ben had impressive spatial ability on BAS-III, but the closest comparison on WISC suggested good but not outstanding ability in Andrew (estimated visual processing 111). Andrew was a confident and quite articulate personality, while Ben was shy and rather withdrawn in assessment and in class.

Attainment data (standard scores) and data from Butterworth's Dyscalculia Screener is detailed in Table 2.

The attainment and screener data thus diverged: although both were better at calculations than problems, Andrew was much stronger at both. The two Singapore maths samples were constructed to involve very similar numbers and the same problem format except for one giving 4 alternatives and the other only expecting an answer. Andrew did better on the multi-choice format, probably because it forced him to consider whether his own answer was satisfactory; he was consistent in the types of question he got right across the two forms. He was very quick and accurate on the screener, and this was consistent with a good score on the WIAT fluency tests. Ben seemed at first to be responding satisfactorily to the screener but the outcome was effectively: "don't

Table 1: Background Cognitive and Reading using standard score data for Grade 1 children

Name	Age	Grade	Cognitive Ability	Verbal Ability	Non-verbal Ability	Spatial Ability
Andrew	6:11	1	106 W*	92 Li	115 D	-
Ben	6:09	1	107 B	81 B 73 Li	115 B	123 B

Name	Age	Working Memory	Processing Speed	Other disabilities	Word reading	Reading Comp'n
Andrew	6:11	87 D	136 D-SIP	ADHD	105 W*	90 W*
Ben	6:09	95 B	113 B-SIP	Lang, mild attention	99 W*	66 LC*

[W= Wechsler tests, B = British Ability Scales III, D = Differential Ability Scales II, Li = Listening Skills Test, LC = Listening Comprehension from WIAT, * = from previous assessment information]

Table 2: Maths attainments and dyscalculia screening data for Grade 1 children:

Name	Math Problem	Number Operations	Fluency	Mental Arith	Screener: Addition 0-9	Screener: Multiplica tion 0-9	Screener: Reaction Time
Andrew	97	124	147	105	9	9	8
Ben	78*	105*	95	-	2	-	-

Name	Screener: Dot Enumeration	Screener: Number Stroop	Screener: Diagnosis	Singapore maths: multi-choice /10	Singapore maths: direct answer /10	Singapore maths: direct answer /10
Andrew	9	9	Not dyscalculic	6/10	3/10	3/10
Ben	2	2	Random responding, cannot diagnose	3/10	1/10	1/10

[All attainments data from Wechsler tests, WIATII or WIATIII, * = from previous assessment, all screener data from Butterworth's Dyscalculia Screener]

know" because he made too many "random" responses; his calculations were very unreliable once he moved above 10; and although he got 3/10 right on Singapore multi-choice, a close look at his responses (which were not consistent between the two forms) suggested a random responding element here too.

There was no opportunity for direct observation of Andrew doing maths, but papers from his school suggested scores of over 50% on tests, with a possible pattern showing longer word problems causing problems, especially comparisons between quantities, and some specific skills (such as picture partition problems) consistently causing trouble. With Ben, some informal observation showed he could reliably identify numbers to 99, estimate small quantities accurately using bricks, and use Dienes base 10 materials with support to represent larger numbers accurately.

The conclusions were thus different. Both had some mild working memory weakness, perhaps associated with attention difficulties, and in different circumstances could go too fast, especially Andrew. Both had some difficulty understanding word problems, associated with weaker language ability especially Ben, but when he could use problem, and thus to difficulty understanding vital new concepts, especially place value at the P1 stage. Both had become a little doubtful of their abilities, with Ben much more generally unsure and Andrew especially stuck on double digit subtraction. Andrew did not seem to lack number sense; Ben's number sense was not so clear, but he seemed very stuck on the meaning of tens and units. Both needed help. In Ben's case the best way to convey his need was to suggest that he was "dyscalculic at present", in line with the Singaporean Ministry of Education expectation that disabilities may be overcome, in spite of the usual expectation that a "diagnosis" is unlikely to alter over time. In other words, he needed recognition and help and with help might overcome this difficulty in time. In Andrew's case, his impulsivity seemed to be the main factor affecting maths learning, so an additional label did not seem necessary.

2. A Primary 3 child with severe doubts about his maths abilities

Data on Carl is a little more restricted, because he was visibly unhappy to work in the first session and wanted to put his head on the desk and say nothing in the second. He had shown some difficulties with reading in Kindergarten but had eventually caught up, and then in P1 shown signs of reluctance to attend school. He was quiet and anxious. In P3 the maths had become harder and he was showing signs of real difficulty with word problems and to be quite slow to learn number facts and multiplication bonds. He passed P2 maths (over 50%) but so far in P3 was doing badly (latest exam 21%).

Background ability data is detailed in Table 3.

Carl's overall ability was at the low end of average, and this seemed to be mainly because of less strong verbal ability. But he was very good at recalling sequences of digits (on BAS-II). Unfortunately his reluctance to engage in the second session prevented further direct investigation of these vital areas, but there was an important difference in his literacy: while word reading was excellent, comprehension was only average. This seemed to link to the verbal ability weakness on BAS-III. He was quick on SIP, and working memory did not seem to be a problem in his case.

Attainment data and data from Butterworth's Dyscalculia Screener is detailed in Table 4.

As expected from the verbal and reading comprehension results, Carl did much less well on Math Problem Solving; he made some calculation slips and mistakes on problems, and reached his understanding limit on fractions and rotation of shapes. He was better at pure calculations, again with some slips on subtraction and weaknesses in times tables. Fluency was surprisingly low. Although the Butterworth Screener said dyscalculia was unlikely, his weakest area was Dot Enumeration, the most pure test of the number sense theory, and this seemed to make sense of his weak fluency and reported difficulty getting number facts and bonds to automaticity.

Table 3: Background Cognitive Ability data for a P3 child:

Name	Age	Grade	Cognitive Ability	Verbal Ability	Non-verbal Ability	Spatial Ability
Carl	8:06	3	86 B	74 B	94 B	98 B

Name	Age	Working Memory	Processing Speed	Other disabilities	Word reading	Reading Comp'n
Carl	8:06	109 B	130 B-SIP	Mild school refusal	130 W	102 W

[W= Wechsler tests, B = British Ability Scales III, D = Differential Ability Scales II, Li = Listening Skills Test, LC = Listening Comprehension from WIAT, * =from previous assessment information]

Table 4: Maths attainment data and dyscalculia screening data for a primary 3 child;

Name	Math Problem	Number Operations	Fluency	Mental Arith	Screener: Addition 0-9	Screener: Multiplication
Carl	95	109	86	-	4	-

Screener: Reaction Time 0-9	Screener: Dot Enumeration 0-9	Screener: Number Stroop 0-9	Screener: Diagnosis
5	3	6	Dyscalculia "not likely"

[All attainments data from Wechsler tests, WIATII or WIATIII, * = from previous assessment, all screener data from Butterworth's Dyscalculia Screener]

concrete apparatus or see the problem, he was stronger. Andrew's attainments on normative and Singapore maths were average or above, while Ben's were particularly weak on word problems, in which much Singapore maths is framed. Andrew's difficulty seemed most strongly associated with his impulsivity (ADHD), while Ben's was more closely linked to a primary language comprehension

The second session began using WISC Block Design as a warm-up, because it is essentially non-verbal, and seemed likely to be an activity Carl would succeed at. He showed considerable uncertainty about some of the problems, and it became possible to prompt him to "try changing this a little and see if that helps"; it did and so it was possible to say to him that he can solve problems. He then tried some Singapore maths, and although he was unwilling to verbalize it was clear that he often went off on the wrong track. Dienes apparatus was used to make the problem concrete and visible, and although close support was necessary, he seemed to be able to reach solutions using the apparatus. It was possible to conclude optimistically that he can learn to deal with problems if he receives help to see what they mean.
The conclusion was that he shows "some indications of dyscalculic difficulties, which are likely to become more severe (because of the cumulative nature of the maths curriculum) unless action is taken to improve his skills and regain confidence in himself as a maths learner." This intermediate conclusion seemed justified because problem solving is only a little weaker than average at present, and the likely explanation (limited verbal ability linked to general anxiety and specific doubt about himself as a maths learner) implies greater plasticity.

3. Two children approaching PSLE

The Primary School Leaving Examination (PSLE) is very important indeed in Singapore education: it functions as the Eleven Plus used to in most of England, to sort children into streams and form the basis for all secondary education admissions. Unlike the 11+, it mainly comprises tests of attainments in all three core subjects, English, Maths and Science.

The two children, Daphne 11¾ in P6 and Ernest, just 11 in P5, had experienced difficulties for some time, Daphne probably since P2 when other girls in her class called her "stupid" and other names in maths lessons, Ernest for about 2 years as his scores and confidence began to dip. In both cases parents wanted to know if there was a serious problem or did they just need more or better tuition.

Background ability data is detailed in Table 5.

The children differed in their cognitive profiles: Daphne had overall average ability with slightly better verbal skills, while Ernest was above average overall, strong non-verbally with about average verbal ability. Working memory was fair to good in both cases, and this was somewhat surprising in Ernest, whose parents had noted he still tended to use his fingers while calculating. Daphne was particularly quick in handling visual symbols. Reading was not a concern for either child.

In both cases, actual maths attainments on US tests were good or above average, and in a small sample of Singapore maths problems there was also reasonable consistency and attainments. Ernest did seem to have relatively slow maths fluency, and he was observed to use fingers and sub-vocalize sometimes when doing calculations. This

Table 5: Background ability data (in standard scores) for two children approaching PSLE

Name	Age	Grade	Cognitive Ability	Verbal Ability	Non-verbal Ability	Spatial Ability
Daphne	11:08	6	103 W	114 W	97 W	-
Ernest	11:00	5	120 D*	106 D*	130 D*	115 D*

Name	Age	Working Memory	Processing Speed	Other disabilities	Word reading	Reading Comp'n
Daphne	11:08	109 W	125 W	None	-	105
Ernest	11:00	116 W	118 D-SIP*	None	113 D*	115 W*

[W= Wechsler tests, B = British Ability Scales III, D = Differential Ability Scales II, Li = Listening Skills Test, LC = Listening Comprehension from WIAT, * =from previous assessment information]

Table 6: Maths attainments and dyscalculia screening data for pre-PSLE children:

Name	Math Problem	Number Operations	Fluency	Mental Arith	Screener: Addition 0-9	Screener: Multiplication 0-9
Daphne	112	124		105	7	8
Ernest	123	138	99	110	5	6

Screener: Reaction Time	Screener: Dot Enumeration	Screener: Number Stroop	Screener: Diagnosis	Singapore maths: multi-choice /10	Singapore maths: direct answer /10
6	6	9	Not dyscalculic	6	7
6	6	7	Not dyscalculic	6	6

[All attainments data from Wechsler tests, WIATII or WIATIII, * = from previous assessment, all screener data from Butterworth's Dyscalculia Screener]

was perhaps associated with slightly lower scores on some of the Butterworth tests. Both children did present concerns to their parents and teachers but these seemed to be a result of not understanding some key topics very well (especially ratio, fractions and percentage). Daphne was not very keen to return for a second session but she did; she needed to say she didn't know why she was coming because she didn't feel there was anything wrong with her. This was an extremely helpful question, because I was able to reply that there wasn't anything wrong. She did, however, need to focus on some topics in maths as part of tuition. Similarly Ernest needed to improve his understanding but he did not seem to have any developmental disorder.

4. Three children at the early secondary stage

Two girls, Fanny and Grace, were both in their first secondary year, and neither was dyslexic (although earlier Fanny had been described as having Irlen Syndrome and ADD), but Ho, a boy, had recently graduated from several years of tuition in a dyslexia programme, and was in the second secondary year. All three had expressed unhappiness with maths over time – they were finding it quite difficult; Fanny was supposed to receive some extra classes in school (but she tended to avoid them), Grace had just started with a new tutor, which seemed promising, while Ho was not having any maths tuition currently.

Their background data is detailed in Table 6:

Grace presented as bright and quick. Her verbal ability was higher than Fanny's, while her spatial ability was quite low. Fanny seemed to present more as a low average ability child, and her attention difficulty was said to be very evident in class. They were also different in the kind of motivation they seemed to have: Grace was very determined, wanting to learn how she could find better ways to handle the maths, while Fanny seemed to be accepting the adults' view of her as ADD; she commented that she "just hated maths, anyway". Ho was good average in most areas, with somewhat stronger non-verbal than verbal abilities. Both Ho and Fanny were good word readers with weaker comprehension skills. I didn't test Grace in those areas.

In retrospect, the assessments of both Fanny and Ho would have benefited from including the Dyscalculia Screener, because both young people had problems with calculation skills; in their cases, assessment was not mainly focused on maths, while for Grace this was the focus. Grace was in fact usually very good at calculations, and was also taking a lot of initiative to find ways to tackle problems. She felt quite strongly that she had a problem but was tackling it vigorously. I considered that her efforts needed some recognition so I felt it best, after listing her considerable strengths, to say that she also had some difficulties with maths, including her weak spatial ability, the lower scores on the pure number sense tests of the screener, her high anxiety and sometimes quickness combined with rigidity of thinking style which hindered her problem solving style, and these amounted to "dyscalculic features". Fanny's difficulties were

Table 5: Background ability data (in standard scores) for two children approaching PSLE

Name	Age	Grade	Cognitive Ability	Verbal Ability	Non-verbal Ability	Spatial Ability
Fanny	13:0 yrs	Sec1	84B	94B	82B	82B
Grace	12:07 yrs	Sec1	93B	109B	95B	78B
Ho	13:08 yrs	Sec2	113W	106W	115W	-

Name	Age	Working Memory	Processing Speed	Other disabilities	Word reading	Reading Comp'n
Fanny	13:0 yrs	121B	108B	ADD Irlen Syndrome	117	101
Grace	12:07 yrs	113B	145B	None	-	-
Ho	13:08 yrs	110W	109W	dyslexia	109	91

[W= Wechsler tests, B = British Ability Scales III, D = Differential Ability Scales II, Li = Listening Skills Test, LC = Listening Comprehension from WIAT, * =from previous assessment information]

Table 6: Maths attainments and dyscalculia screening data for early secondary children:

Name	Math Problem	Number Operations	Fluency	Mental Arith	Screener: Addition 0-9	Screener: Multiplicati on 0-9
Fanny	103	96	90	90	-	-
Grace	122	124	134	-	8	7
Ho	108	90	-	105	=	-

Screener: Reaction Time	Screener: Dot Enumeration	Screener: Number Stroop	Screener: Diagnosis	Singapore maths: multi-choice /10	Singapore maths: direct answer /10
-	-	-	-	4/4	¼
3	4	5	No	10/10 at P6	7/10 at P6
-	-	-	-	-	-

[All attainments data from Wechsler tests, WIATII or WIATIII, * = from previous assessment, all screener data from Butterworth's Dyscalculia Screener]

perhaps understandable as part of a more general learning difficulty, while Ho had particular difficulties with calculations, and particular concepts seemed not to have been properly grasped; he also seemed to have become discouraged about learning maths, and his motivation to improve was not strong.

5. Two children at the College stage:

Isobel and Julie were both 17 but in rather different situations. Isobel had left school about a year previously and done a vocational course at a college; she hadn't much enjoyed it and wanted to return to college to do other courses, but was worried she would need a pass in maths or obtain an exemption. Julie had taken the prestigious Junior College route and so had to study maths even though she had always found it hard. She was now studying maths A level, and finding she was spending longer working on the maths than on other subjects, while only just scraping through, in spite of the close support of a personal tutor.

Background data on these young women is detailed in Table 7.

Their cognitive ability profiles are not very different, both having very strong verbal abilities, and both less good non-verbal abilities. Indeed, the difference for Isobel was very marked (51 points between verbal and spatial abilities). Isobel also had lower working memory and processing speed. Julie varied in her speed of doing things, while Isobel was mostly quite a slow worker. Both were

Table 7: Background ability data (using standard scores) for two young people at college;

Name	Age	Grade	Cognitive Ability	Verbal Ability	Non-verbal Ability	Spatial Ability
Isobel	17:02 yrs	College	Range too great	129D	84D	78D
Julie	17:07 yrs	College	110D	121D	106D	100D

Name	Age	Working Memory	Processing Speed	Other disabilities	Word reading	Reading Comp'n
Isobel	17:02 yrs	80D	73D	No	102W	107W
Julie	17:07 yrs	108D	102D	No	-	117G

[W= Wechsler tests, B = British Ability Scales III, D = Differential Ability Scales II, Li = Listening Skills Test, LC = Listening Comprehension from WIAT, G = Gort Silent Reading Test, * =from previous assessment information] satisfactory to good at reading.

Maths and screening test data is detailed in Table 8.

Julie was able to achieve at above average levels on the American maths tests I had available; her speed on the fluency tests was also good, and she achieved good scores on the dyscalculia screener at a 14 year old level (there was no screener available for a 17 year old at that time). I was not able to see her current maths performance on A level materials. But her descriptions of her struggles over time with maths, including at present, were authentic: she had to work very hard to be able to solve the problems she was given and she did so by learning a procedure and following it very assiduously, with some help from her tutor; she didn't do well in class tests but when she had time for prolonged revision she was just able to pass. It seemed to me that her uneven abilities (good verbal but average non-verbal and spatial) together with some other difficulties she described (eg recognizing faces, working out routes and directions) could best be seen as a "mild non-verbal learning disorder", and that this was a good enough explanation of her maths learning difficulty.

Isobel had been ungraded in her final school exams in maths. Her current skills were very weak, even allowing for the year when she had not been studying any maths. She also impressed as someone who was struggling with difficulties, which

Table 8: Maths attainments and dyscalculia screening data for 2 young people attending college

Name	Math Problem	Number Operations	Fluency	Mental Arith	Screener: Addition 0-9	Screener: Multiplicati on 0-9
Isobel	77	81	72	-	-	-
Julie	120	119	113	110	6	9

Screener: Reaction Time	Screener: Dot Enumeration	Screener: Number Stroop	Screener: Diagnosis	Singapore maths: multi-choice /10	Singapore maths: direct answer /10
-	-	-	-	Unable to do any Singapore Sec 3 maths problems	
2	6	9	Unlikely	A level maths problems not readily available	

[All attainments data from Wechsler tests, WIATII or WIATIII, * = from previous assessment, all screener data from Butterworth's Dyscalculia Screener]

in her case seemed more severe. She tried to do some maths problems at a 14 year old level, and had to bring them back saying she couldn't do any. It seemed as though the bigger disparity between verbal and non-verbal abilities and her quite slow processing speed and weaker working memory combined to make learning maths almost impossible beyond about a 9 year old level. I suggested her difficulties should be described emphatically as "severe dyscalculia."

6. Other children where maths difficulties were part of a more general assessment:

These children add to the range of patterns of abilities and needs which are considered in forming judgements about MD/dyscalculia. An important group of students, Ken (10), Patrick (17) and Richard (18) were within or on the borderline of children with moderate general learning difficulties. Could they therefore be described as also MD/ dyscalculic? In fact two of them had been previously assessed and had been described as dyslexic, so it seemed illogical not to also describe them as MD/dyscalculic when their maths difficulty was as great as their literacy weakness. Since Stanovich's strong argument against discrepancy assessment for dyslexia (Stanovich 1991), I have argued that even children with general LD can also have a specific difficulty with reading – if not, they may be denied exam accommodations and teaching help which will benefit them. Although the case against discrepancy assessment for MD/dyscalculia has not been made, it seems that the arguments for special weaknesses in MD/dyscalculia, such as number sense, working memory, verbal reasoning, and spatial ability are essentially similar to the argument that Stanovich put forward, namely that IQ is a poor predictor of word reading and so a discrepancy between it and reading was irrelevant to reading achievement. So it seemed both educationally appropriate and logical to allow that they might have MD/dyscalculia as well as dyslexia. In Richard's case, he had developed a strong dislike of maths, and his problem solving was weak, but calculation skills were about average, so I felt it would be unhelpful to label him as dyscalculic, in case this functioned as an excuse not to learn or as an excuse not to teach him. He might in good hands at the college level do better if he really needed maths skills.

Marcos was in the early secondary stage and probably had struggled because of a combination of second language and auditory processing difficulties. He was now doing better in school, and although he felt maths was still his weakest area, I felt he too would be best seen as capable of overcoming his difficulties, especially with a focus on the language of maths problems; in fact his WIAT-III maths scores were all close to average.

I gave nuanced judgements on several others. Lianne was dyslexic, and her score on WIAT maths problems was low; on the Butterworth screener she got 3's and 4's but the programme said she wasn't dyscalculic. I felt she did have particular problems with working memory (low WMI on WISC-IV but also low mental arithmetic), and with processing speed, nor did she have much confidence in her own maths ability. So I suggested she had "mild dyscalculia". Oliver had quite severe dyslexia but he was verbally very able and was making quite good progress educationally; maths was still quite a problem for him. His weakness on the fluency tests and a big difference between good verbal and lower non-verbal abilities (30 points) justified describing him as having "dyscalculic features". Similarly Vernon had been described as dyslexic, but he was also a long term intermittent school refuser who probably also had general anxiety difficulties associated with Asperger Syndrome. He did not believe he was able to do maths, but in fact did some calculations and types of problems reasonably well. His working memory was also a weakness. I felt it would help him to be seen as having some dyscalculic features, so drawing attention to his learning difference but hopefully not preventing sustained effort.

I suggested that previous assessment had been wrong about Wendy, who had been described as dyslexic, dysgraphic and dyscalculic on the basis of a discrepancy between the performance IQ of a very old version of WISC on which she had achieved a very high score. In fact her spelling was still weak but reading and maths were at average levels, so I argued that she should not been seen as dyscalculic. In 3 of four other cases, I suggested that the children were dyscalculic because of a combinations of working memory, verbal comprehension, fluency and self-doubt issues. In one other case, where a 9 year old boy was clearly dyslexic but was doing somewhat better in maths, I felt there was not a clear enough case for a dyscalculia label, although he was below average on the WIAT-III tests.

Discussion: implications of these cases for research, analysis and assessment.

1. Psycho-educational assessment of MD:

Recent books (Chinn, 2012; Henderson, 2012) have provided a helpful overview and much specific material for MD assessment. The cases reported here were a mix of specific MD assessments and more general assessments, and so time available for assessment undoubtedly played some part. More thorough assessment is possible if there is a specific maths focus. Especially this means making time for informal observation and exploration, as both Chinn and Henderson advocate.

Both WISC-IV and BAS-III (or DAS-II) have strengths and weaknesses for MD assessment; if language is a potential issue, then WISC seems to offer more, and working memory is also more straightforwardly assessed in WISC. If spatial or other aspects of non-verbal abilities are more salient, then BAS or DAS may be more useful, and they are usually quicker.

When using maths tests in Singapore, it is essential to go beyond US or UK normed material because most children in Singapore will do well on it. Material which takes account of both the Singapore curriculum and its strong focus on word problems is necessary. This may not be the case in other places which are more similar to the countries where maths assessments are normed, although there remains a need for efficient assessments

of word problems and for ways of assessing maths vocabulary knowledge.
The computer based screener from Butterworth certainly adds to the picture in ways that pencil and paper or oral assessment cannot. As the cases above illustrate, sometimes the evidence from other sources goes contrary to the screener results, and so the programme verdict has to be questioned. In all cases it helps to "triangulate" results.

Given the possible importance of working memory, there may be a need for measures of it which do not rely on digit tests. There may also be a need for tests of verbal and non-verbal reasoning which explicitly do involve numerical and other quantitative domains. There may be, more generally, some significant longer-term benefit of consistency in being able to scale strengths and difficulties across all relevant psycho-educational areas (especially attention and motivation), given the significance now accorded co-morbidities.

2. Diagnostic criteria and labels:

Diagnostic criteria set by researchers, teachers, special education administrators and exam boards all serve somewhat different purposes. It seems extremely likely from recent research that a continuum rather than a categorical system reflects best the reality of children's differing needs, but even researchers often need to say that children either are or are not dyscalculic (Hulme & Snowling, 2009). Similarly, they also prefer to exclude children with more general LD. The levels of difficulty at which exam accommodations can be justified and additional interventions are funded are important and are likely to become more regulated as MD/ dyscalculia becomes better studied and identified. At present, my approach, which takes account of levels of difficulty on US norms but also seeks direct observation of maths work on the Singapore curriculum, enables me occasionally to say that a young person has some degree of dyscalculia even if they can do US tests fairly well; this is partly because Singapore word problems are very different and substantially harder in most cases. I am thus elevating a judgement about a child's subjective difficulty above the information from normed assessment. Ideally I would like this option to continue to be available, but I expect it will be removed in time. There is of course a danger that psychologists will advocate exam accommodations for children who are perceived in a broader educational context as undeserving. However, it is essential that normed materials satisfactorily and fully encompass the range of learning challenges that children face, and that the norms can be justified in each country.

I have always considered that labels can be but are not always socially and educationally helpful. The balance needs to be weighed, usually with the parents. If a school is unable to adapt its teaching and provide appropriate support and exam accommodations, then a label may mean to some teachers that a child will be too difficult to teach, and so may be unhelpful. Or the child may reject the suggestion that they have a "condition". But sometimes the label serves as a way of explaining a potentially or actually depressing learning difficulty which can be dealt with better if it is set out openly.

The broader context also makes a difference: in Singapore, a diagnosis is required for dyslexia, if exam accommodations or publicly funded help are needed, so there is an expectation that nothing short of medical model labelling is significant. And most children can and do receive additional tuition, so a recommendation for additional help is normal, whatever the level of difficulty.

In spite of the pressures for labelling, it may be helpful to retain some scaling of difficulties. From the cases presented, an appropriate three-step scale is "mathematical learning difficulties", "dyscalculic features" and for the most severe cases "dyscalculia"; this may be closer to current research thinking (eg Dehaene, 2011, p275-6) than qualifiers such as mild, moderate or severe dyscalculia.

3. Other disabilities and diagnosis

This is likely to remain quite a difficult issue to regulate. Recent developments in research thinking (eg Hulme & Snowling, 2009) emphasize a new sense that many or even the majority of children have more than one disability. How psychologists and other professionals should explain multiple difficulties is far from clear: can a pre-existing language difficulty/disorder, general learning difficulty or attention deficit account fully for a child's maths difficulties? The cases illustrate both some situations where prior difficulties seem to provide sufficient explanation and others where they do not. Just where the lines should be drawn is not very clear, and might not be clearer even if each child were simultaneously assessed by a multi-disciplinary team (which is sometimes suggested as a way of handling complex cases).

An assessment ideally brings together information from multiple sources, and provides a coherent explanation of what difficulties the child experiences. Occam's Razor sometimes needs to cut through lists of overlapping difficulties, which are often intended to show a child needs much extra help. There should ideally be no rule that says how many disabilities a child can have, or even which is primary, but the assessment is most effective if the explanation makes sense, and leads to the right kinds of help in the right order.

4. Curriculum issues

The main cases reported here are of Singaporean young people, and the special qualities of Singapore maths demonstrably make a difference to assessment and diagnosis. By extension, the features of any curriculum and teaching strategy should also be considered relevant. Arguably, maths in Singapore is difficult enough to justify quite a lot more assessments of MD and hence more additional teaching and accommodations. There is a need for assessment materials which make clearer the child's response to a particular curriculum. In the Singapore case at the primary stage, this especially means word problems, assessed in both multi-choice and simple answer formats.

5. Interventions and Accommodations

This paper is intended to summarize 10

cases, with some further information about another 12, so there has been little room for details of interventions and accommodations. Intervention research using modern forms (eg Randomized Controlled Trials) in MD is quite limited at present (Hulme & Snowling, 2009), so we mainly rely on the experience of practitioners (eg Miles & Miles, 1992, Chinn etc).

- In all cases there have been elements of addressing the child's own views of their strengths and weaknesses, and this is certainly a theme from experienced practitioners.

- A second major theme has been using concrete materials where symbolic processes and understanding seems weak, before returning to the use of symbols alone. Concrete materials have also been recommended where the focus is on general weaknesses in language and understanding of maths concepts and procedures: this might be called the "multi-sensory teaching" strategy for MD, because a key aim is to enlarge and make more reliable verbally mediated understanding of maths.

- In the absence of a maths vocabulary test, it has not been possible to make this a specific recommendation, but teaching the language of maths (as realized in a particular curriculum) is also a clear need in many cases.

- In some cases, where working memory is a weakness, traditional support strategies (using lists and visual cues, short explanations, rehearsal etc) have been suggested, and for older children direct computer based interventions (such as Cogmed, Gray et al, 2012) have also been mentioned.

- Although calculation speed and efficiency has sometimes been a significant concern, no specific interventions for older children have been suggested. For younger children there are some promising computer based interventions. I am not aware of any research studies of the use the abacus, which could provide another possible approach.

- Generally, there do not seem to be any well-known interventions to support young people whose spatial and non-verbal reasoning abilities seem to be the main cause for the MD. The main recommendation is thus to work around the weakness, expecting the child to require a single, consistent teaching method using verbally explicit concepts and procedures, avoiding alternative ways of tackling the problem.

- Finally for some children who are seen as having some mild MD, they need remediation in particular maths topics and some teaching about study skills, especially estimating and checking solutions.

The main accommodation is extra time, which is particularly important where there is an element of anxiety. For one of the college-level students, it was suggested that she be exempted from a maths qualification for further courses, but I understand colleges are resistant to this. The use of a calculator for sections of exam papers where they are not normally allowed has also been recommended, but whether this is acceptable is not yet clear. It is possible to envisage wider accommodations (by analogy with the use of a reader for a dyslexic student) such as an exam format in which maths problems are presented as pure calculations. It is unlikely that this would be acceptable, and students are more likely to be channelled into types of exam or tiers which are less challenging.

6. Models of Mathematical Difficulties

This paper is not intended to provide evidence to bear on the underlying cognitive explanations of MD. The theory of MD is in any case not yet well developed (Hulme and Snowling, 2009, Dehaene 2011). However, assessment of children's mathematical learning must have some theoretical underpinning and direction – the psychologist needs to have some ideas of what to look for if a coherent and plausible explanation of a learning difficulty is being sought. The results from 10 case studies suggest a shortlist of possible weaknesses:

- Verbal reasoning skills are likely to have a significant impact on mathematics learning, especially where word problems are prominent in the curriculum;

- Non-verbal (especially spatial) reasoning is also likely to be important;
- Working memory is important, as is speed, but not necessarily the same processing speed measures relevant in literacy. The measurement of WM through Digit Span seems on the face of it problematic, because it is relies on speed of recall of digit symbols.

- Impulsivity and the ability to plan consciously (part of Executive Functioning) is probably very important but is not easy to separate out from other cognitive processes, because these processes are so pervasive.

- Numerosity is obviously relevant but is not easy to discriminate from understanding and calculation skills with increasing age.

- Literacy skills need to be checked carefully.

- Acquired maths skills themselves and especially how complete and reliable the children's understanding of them are vital.

- There are probably links between some or all of these areas, which will mean ultimately that some are seen as primary and others as secondary. Intervention research will also show that some weaknesses can be remediated more effectively than others, perhaps more at particular ages or stages.

The most significant conclusion here is therefore that at present a wide range of possible weaknesses need to be considered – there is no obvious "magic bullet" in helping children with MD. But of course, their current maths skills are where a problem usually first becomes evident. Detailed and systematic analysis of their maths skills and attitudes will remain necessary, even if we do find a magic bullet for MD.

Conclusions

This study suggests that in a relatively young field, such as the scientific study of children's mathematical learning difficulties, that case study may have a number of roles to play.

It may suggest where current assessment materials and techniques are adequate (eg broad verbal and non-verbal reasoning tests) and where there are gaps (eg specific quantitative reasoning tests in both verbal and non-verbal domains, and mathematical vocabulary measures).

Individual child case studies necessarily use but also ask questions about labels and criteria. A collection of case studies, as in this paper, thus enables some generalization about the implications for individual children and for educational systems as wholes for particular ways to set criteria and to use continua or diagnostic labels.

Current understanding of the range and interactivity of different developmental disorders clearly has a major implication for research. The hypothesis of very commonly occurring co-morbidities (such as dyslexia and MD) calls for significant research interest in this phenomenon. But educational assessment and teaching practice are also affected by the co-occurrence of learning difficulties. The conclusion suggested here is that multiple diagnoses are to be preferred if they make sense and if common histories and effects on learning can be made clear.
The importance of a particular educational context is well illustrated by considering cases of mathematical difficulties in Singapore, I suggest, because of the generally high standards and expectation upon children, and because of some special features of Singapore maths education. Comparisons with other curricula and contexts may be rewarding.

This paper has only mentioned interventions briefly, with no evidence on their effectiveness. However, it is likely that case study can also contribute to the understanding and selection of the most promising interventions for children with MD.

There are perhaps two possibilities as far as the ultimate understanding of the origins of MD: a single cause (such as numerosity) or multiple causes. This paper could not expect to shed light on this difficult research issue. However, it seems likely that as children develop a relatively wide set of abilities needs to be considered when seeking to understand MD in particular cases. Further case study may then perhaps refine which factors or abilities appear most relevant at different ages, so that researchers can profitably focus their attention in the most enlightening ways, and thus clarify whether one or many factors or pathways are involved.

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