The PRISM Studies:
Improving children’s mathematics skills following very preterm birth

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for the PRISM Study team (see Box 1)

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Competency in mathematics is crucial for many day-to-day activities. Mathematics plays a role in everything from setting an alarm clock, calculating journey times and weighing out ingredients to calculating medication doses and managing household bills. Over recent years there has been growing concern about the mathematics skills of children who were born very preterm (<32 weeks gestation). Although very preterm children have significantly poorer performance than term-born peers across all school subjects, they have greatest difficulties in mathematics.1 The risk for mathematics difficulties increases with decreasing gestational age at birth, such that babies born extremely preterm have the poorest attainment at school. Data from the UK EPICure Study showed that 44% of children born extremely preterm (<26 weeks gestation) had mathematics learning difficulties at 11 years of age, compared with just 1% of their term-born classmates. When children with low average scores were included, 70% of extremely preterm children were found to have low attainment in mathematics by the end of primary school compared with just 14% of their classmates.2 Importantly, and in contrast to reading difficulties, mathematics difficulties are not fully accounted for by the generally lower IQ of very preterm children, which suggests that there is something about mathematics that they find especially difficult.

Why is mathematics so important?
Understanding how very preterm birth affects children’s mathematics skills is of increasing concern as mathematics difficulties, even in early childhood, cast a long shadow over an individual’s life chances. Analyses of birth cohort studies have revealed that mathematics skills in primary school are stronger predictor of a child’s future health, economic potential and employment prospects than attainment in other subjects studied at school, and over and above the educational qualifications they go on to obtain later in life.3 Improving very preterm children’s mathematics skills is therefore crucial not only for improving their attainment at school, but for maximizing their future life chances.

What are the PRISM Studies?
In order to develop strategies to improve very preterm children’s attainment at school, we first need to understand the nature of their difficulties with mathematics and what the underlying causes might be. The PRemature Infants’ Skills in Mathematics (PRISM) Studies, based at the University of Leicester, aim to answer these questions. The studies are led by a multi-disciplinary group of researchers with expertise in developmental psychology, mathematical cognition, neonatology and education who are bringing together emergent
research in these fields to discover the mechanisms that underlie very preterm children’s difficulties with mathematics (Box 1).

Most previous studies in this area have used a single standardised test to assess children’s attainment in mathematics. Standardized attainment tests are norm-referenced measures that provide a snapshot of a child’s overall mathematical ability, but they do not provide diagnostic information or indicate the exact nature of a child’s difficulties. In contrast, the PRISM studies have been designed to provide a more in-depth analysis of mathematical ability by assessing a range of cognitive skills that are known to be important for learning mathematics (Figure 1). These include ‘domain-general’ cognitive skills such as working memory, processing speed, visuospatial skills and inhibition (see Box 2), and a range of ‘domain-specific’ skills that are important for proficiency in mathematics, such as recognising digits, counting, recalling basic number facts, estimating the location of digits on a number line, applying efficient strategies to solve mathematical problems and understanding mathematical concepts.

Recent research in the field of mathematical cognition has also focused on the role of magnitude representations in learning mathematics. Magnitude representations allow children and adults, and even non-human animals, to quickly estimate the quantity of a set of objects without explicitly counting them. This ability is also known as ‘number sense’. For example, in experimental tests called nonsymbolic and symbolic magnitude comparison tasks (Figure 1), we measure the accuracy and speed with which participants can determine which of two sets of dots, or two digits, presented on a computer screen has a larger quantity without allowing them the time to explicitly count each set. The speed and accuracy of an individual’s responses on these tasks is an indicator of how precise their magnitude representations are, that is, how accurately they can form mental representations of quantity. Poor performance on these tasks has been associated poor attainment in mathematics in both children and adults. In particular, many studies have shown that individuals with developmental dyscalculia, a learning disorder characterized by specific and severe difficulties in mathematics, have poor magnitude representations.4

To date, only the PRISM Studies have assessed all of these skills concurrently to try and tease apart the nature and origins of very preterm children’s mathematics difficulties. When the first PRISM Study commenced in 2011, a key question to be answered to advance both theory and practice was whether very preterm children also have deficits in magnitude representations, similar to children with developmental dyscalculia, or whether other cognitive skills underlie their difficulties with mathematics.
The PRISM-1 Study

With funding from Action Medical Research in 2011, 117 very preterm children were recruited from admissions to neonatal care in University Hospitals of Leicester NHS Trust and University College London Hospital. The children were aged between 8 and 10 years at the time of recruitment and all were in mainstream school, commensurate with our inclusion criteria. To form a control group, 77 classmates who were matched for age and sex where possible, and born at full-term, were also recruited. All of the children were visited by a study psychologist, either at their school or at home, who carried out an assessment of their attainment in mathematics using a standardized attainment test called the Wechsler Individual Achievement Test-IIUK. They also administered a battery of standardized and experimental tests to assess the skills shown in Figure 1. In addition to this face-to-face assessment, information about socio-economic status, behavior, attention and emotions, and special educational needs was collected via questionnaires completed by parents and teachers. Despite being asked to participate in a series of mathematics tests and neurocognitive assessments for a full school day the children reported enjoying the experience!

Overall, in line with previous literature, we found that the very preterm children had significantly poorer attainment in mathematics than the children who were born at term, with a deficit of 12.3 points (95% CI -17.9 to -6.6), which equates to a 0.8 SD deficit. This was compared with a deficit of 7.2 points (95% CI -13.0 to -1.3; 0.5 SD) in non-verbal IQ (Figure 2). When adjusting for confounders, we found that the preterm children’s poorer performance in mathematics was not accounted for by their lower IQ or lower socio-economic status.

We also found that, after correction for multiple comparisons, the very preterm children had significantly poorer working memory and visuospatial skills than the children who were born at term. In addition, they had poorer counting skills and more often applied immature strategies to solve simple arithmetic problems, such as counting on their fingers rather than retrieving the answer from memory; these deficits were also independent of their lower IQ. Interestingly, however, we found that the very preterm children did not have poorer performance on the nonsymbolic and symbolic magnitude comparison tasks. This result was pivotal because it showed that the mathematics difficulties of very preterm children did not stem from deficits in magnitude representations and, therefore, have a different aetiology to those of children with developmental dyscalculia. Instead, we found that very preterm children’s poorer proficiency in mathematics was associated with poorer working memory.
and visuospatial skills, which accounted for the deficits in their domain-specific mathematics skills and much of their deficit in attainment. This was a significant finding both theoretically, in advancing knowledge of the cognitive bases of neurodevelopmental disorders, and practically in identifying potential targets for intervention.

The PRISM-2 Study

In 2015, further funding from Action Medical Research enabled us to follow up the PRISM-1 cohort at 12 to 14 years of age. Secondary education imposes greater demands on children’s cognitive resources and the mathematics concepts to be learned become increasingly complex. Adolescence also marks an important developmental transition during which domain-general cognitive processes continue to mature. Therefore, the cognitive impairments of very preterm children may become exacerbated in secondary school, cascading into increasing deficits in mathematics. There is a lack of longitudinal research into preterm children’s mathematics skills and, as yet, no studies have carried out intensive phenotyping of the mathematics skills of very preterm adolescents.

We are currently re-assessing the PRISM-1 cohort at 12 to 14 years of age using the same methods as in PRISM-1. The aims of this new study are to find out how the very preterm children’s cognitive and mathematical skills have developed over time and to determine whether mathematics difficulties in secondary school have the same underlying causes as those of very preterm children in primary school. As might be expected, our domain-specific mathematics tests had to be updated to reflect the mathematics abilities of 12-14 year olds, which was done to allow assessment of all of the same aspects of mathematical cognition that were tested in primary school but at a more advanced level. In addition, geometry and algebra tasks were added to the test battery as these subjects form a substantial part of the Key Stage 3 and 4 mathematics curricula. With the help of Dr Steve Wardle and the neonatal clinical team at Nottingham University Hospitals NHS Trust, we have also recruited an additional cohort of very preterm adolescents to the study to increase our statistical power for cross-sectional analyses.

To date, we have achieved a 71% follow-up rate of children who took part in PRISM-1 and, together with our new sample, we have recruited 132 very preterm and 99 term-born adolescents to take part. The study assessments have been taking place at secondary schools and participants’ homes throughout 2016 and we are now coming to the end of the data collection phase. Analysis and dissemination of the study results will commence in 2017 and we eagerly await the findings.
From observation to intervention
A further key aim of the PRISM-2 study is to use the information gained about the nature and origins of very preterm children’s mathematics difficulties to develop an intervention to help students who struggle with mathematics at school. As the results of the PRISM-1 Study indicated that very preterm children’s difficulties are different in nature to those of individuals with developmental dyscalculia, existing interventions designed to improve magnitude representations that were developed for children with developmental dyscalculia are unlikely to be effective in this population. A number of recent research studies have also focused on the efficacy of working memory training programmes for improving children’s performance at school. Whilst these typically show short term benefits in improving children’s working memory, there is as yet no good evidence of transfer to improved performance in mathematics. Therefore, we are taking a different approach to intervention.

Two children in an average sized UK primary school class are likely to have been born preterm. Despite this, the results of a recent survey conducted by members of the PRISM Study team showed that teachers lack knowledge and training about the developmental and educational needs of children born very preterm. Only 16% of teaching staff surveyed had received any training about children’s outcomes following very preterm birth, and over 85% reported that they would like more information in this area. Strikingly, the survey found that teachers’ poorest area of knowledge related to the high risk for mathematics difficulties following very preterm birth, suggesting that very preterm children may not be receiving appropriate support in the area they need it the most. Improving teachers’ knowledge of very preterm children’s outcomes and providing them with the practical skills they need to adapt the environment to support the education of very preterm children represents an alternative approach to intervention.

During 2017, we will develop and pilot a novel, multi-media e-learning programme for use by teachers, the content of which will include training about the long term impact of preterm birth on children’s development and learning, tips on how to identify children with cognitive and mathematics difficulties and, crucially, information about practical strategies teachers can use to scaffold very preterm children’s learning in the classroom. Although initially targeted at supporting learning in mathematics, the strategies provided may help support learning in other school subjects. The intervention will be designed in collaboration with teachers, educational psychologists and e-learning experts and will be piloted and evaluated in 2018. Ultimately, with further development and evaluation, we hope this will
improve not just the academic achievement of very preterm children, but their future life chances.

**Keywords:** preterm birth; mathematics; domain-general skills; education.

**Key points:**
1. Children born very preterm are more likely to struggle with mathematics than with other school subjects.
2. Very preterm children’s mathematics difficulties have a different aetiology to Developmental Dyscalculia.
3. Very preterm children’s mathematics difficulties stem in part from poor working memory and visuospatial skills.
4. An intervention that provides teachers with strategies to support very preterm children’s learning at school is currently under development.
Key references


Box 1. The PRISM Study team

- Samantha Johnson, Chief Investigator & Reader in Developmental Psychology, University of Leicester.
- Camilla Gilmore, Reader in Mathematical Cognition, Loughborough University.
- Lucy Cragg, Assistant Professor in Developmental Psychology, University of Nottingham.
- Neil Marlow, Professor of Neonatal Medicine, University College London.
- Victoria Simms, Lecturer in Developmental Psychology, Ulster University.
- Rose Griffiths, Professor of Education, University of Leicester.
- Heather Wharrad, Professor of E-Learning and Health Informatics, University of Nottingham.
- Sarah Clayton, Post-doctoral Research Associate, University of Leicester.
- Rebecca Spong, Research Assistant, University of Leicester.
- Emma Adams, Study Administrator, University of Leicester.
Figure 1. Domain-general cognitive abilities and domain-specific mathematics skills assessed in the PRISM Studies, in addition to attainment in mathematics.
Box 2: Domain-general cognitive skills

Domain-general cognitive skills are a range of cognitive processes that allow us to regulate our behaviour in order to achieve goals and to respond flexibly to changes in our environment. Deficits in these core cognitive processes have frequently been associated with achievement at school. Below are brief definitions of the domain-general skills assessed in the PRISM Studies.

**Working memory** – The ability to store and manipulate information in the mind for a short period of time. Working memory is different to short-term memory as it requires both remembering information and operating on it, such as remembering a list of numbers then repeating the list back in the reverse order. Working memory is involved in multi-step calculations where interim solutions must be held in mind, for example, in a multi-digit mental arithmetic problem, calculating and holding the sum of the units in mind whilst calculating the sum of the tens.

**Processing speed** – Processing speed refers to the time it takes a person to perceive, mentally process and respond to stimuli in the environment. It is a measure of how quickly the brain processes incoming information. Faster processing speed means mathematics problems can be solved more fluently and under time pressure.

**Visuospatial skills** – Visuospatial skills refer to the ability to interpret visual information relating to the location of objects in space. This is also sometimes referred to as hand-eye coordination. Visuospatial skills are important for drawing relationships between objects, for example, in mathematics visuospatial skills are important for reading and interpreting graphs.

**Inhibition** – Inhibition refers to the ability to respond to relevant information in the environment whilst ignoring distracting irrelevant information. Inhibition is required not only to ignore distractions at the classroom level (e.g. noise or chattering in the background), but also to disregard salient mathematical information that is not relevant. For example, when counting we learn that 4 is a larger number than 2, but when using fractions we have to inhibit this information to learn that ¼ is smaller than ½.
Figure 2. Mean differences (99.64% confidence interval) of z scores between very preterm children and term-born children on tasks measuring mathematics, domain-general cognitive skills and domain-specific mathematics skills. (Reproduced with permission from Simms et al., Nature and origins of mathematics difficulties in very preterm children. A different etiology than developmental dyscalculia. Pediatric Research 2015;77:389-395.) PERMISSION NEEDED TO REPRINT