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Loughborough University
Centre for Mathematical Cognition

UKRI Economic and Social Research Council

# Mathematical Cognition: Latest research and implications for assessment

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# Introduction

- Mathematical cognition is the study of the cognitive processes involved in learning and doing mathematics.
- Understanding these cognitive processes is helpful (but doesn't tell us everything).
- Explaining variation in mathematical outcomes more broadly will help us to better understand why some learners have particular difficulties

Terminology: I will use the term "mathematical learning difficulties" (MLD) rather than SpLD or dyscalculia.

# Outline & take-home messages

1. Mathematics is multi-componential and hierarchical and involves bringing together a complex set of skills.
2. This includes basic mathematical processes that are specific to mathematics:

   e.g. numerical magnitude processing
3. Also includes general cognitive skills that are involved across many domains.

   e.g. inhibition and spatial reasoning
4. Learning happens within formal and informal learning environments.

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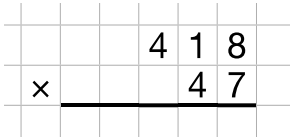
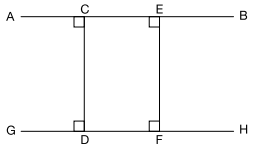
# Part 1: Mathematics is multi-componential and hierarchical

# Let’s look at some maths:

689 + 38 =




Tick **all** the correct statements.

- AB is parallel to CD ☐
- GH is parallel to AB ☐
- CD is perpendicular to GH ☐
- EF is perpendicular to CD ☐

Mrs Mills has **940** seeds to plant into trays.

She plants **12** seeds in each tray.

The last tray is not full.

What **fraction** of the last tray is filled?

## What is required?

- interpret symbols
- read, identify and hold in mind relevant information
- carryout procedures accurately
- plan multi-step strategies
- know concepts
- interpret spatial information
- …

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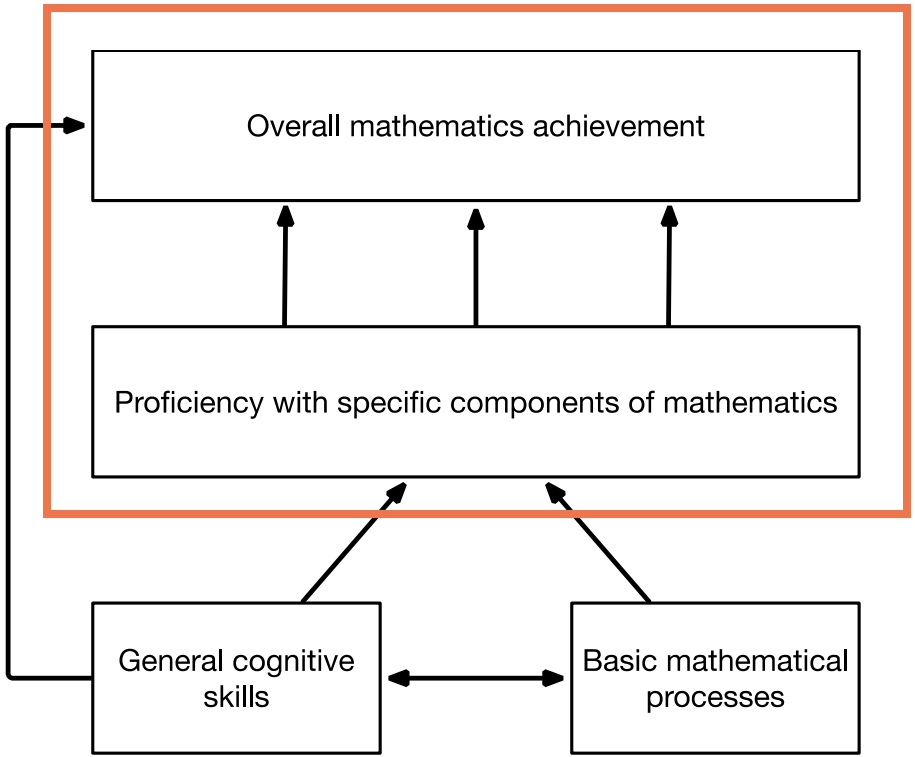
# A framework for thinking about mathematics

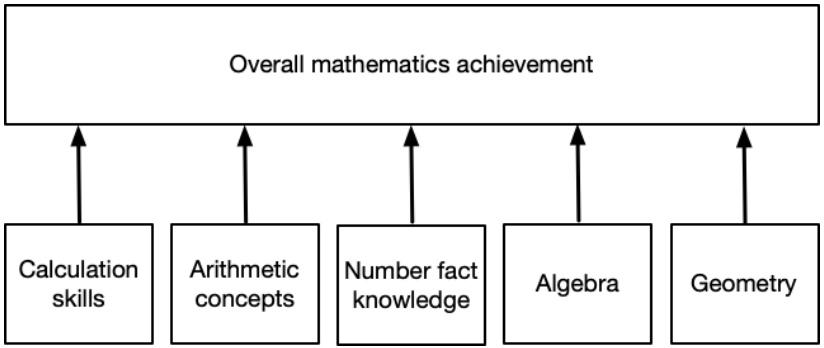



Why is it important to think about these different components?

Gilmore, (2023)

# Multiple components

95 pupils aged 12 to 15:




Spiller et al., (2023)

Why this matters

- Mathematics is not hierarchical in a simple manner.
- Learners have different patterns of strengths and weaknesses.
- Overall achievement might not tell you where areas of difficulty are.
- Learners need the opportunity to develop different components.

To understand MLD we must consider the multi-componential nature of mathematics.

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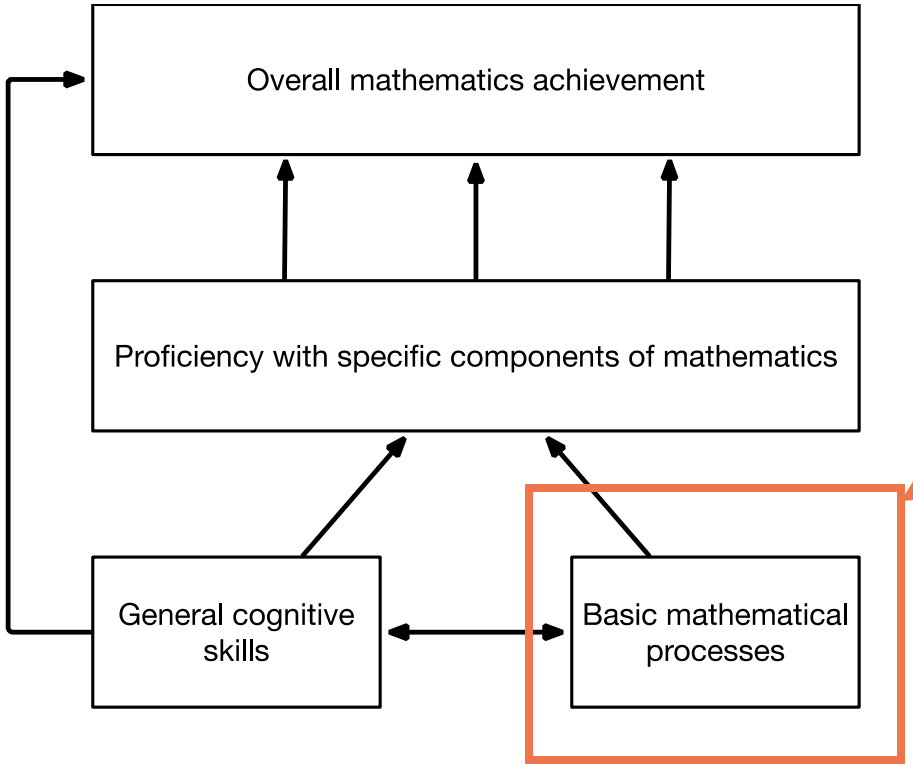
# Part 2: Mathematics draws on basic mathematical processes.

# A framework for thinking about mathematics:




Numerical magnitude processing

Order processing

Subitising

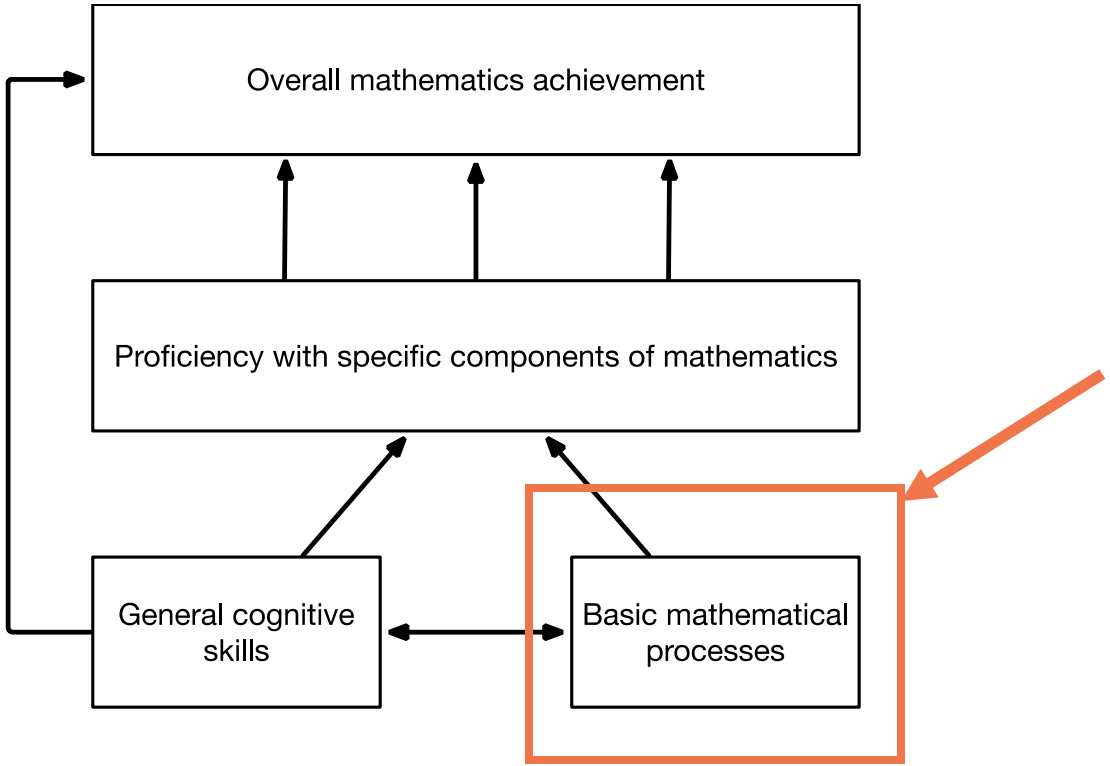
Symbol knowledge

Symbol transcoding

…

Gilmore, (2023)

# A framework for thinking about mathematics:




Numerical magnitude processing

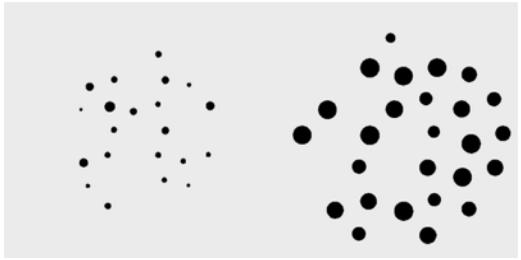
Gilmore, (2023)

# What is numerical magnitude processing?

The ability to represent and process approximate quantity information.

This includes:

- Non-symbolic magnitude processing - which is present from birth and becomes more precise over childhood.
- Symbolic magnitude processing – which is about assigning magnitude information to number words and symbols



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# Numerical magnitude research

Many studies find that individual differences in numerical magnitude processing are associated with mathematics measures.

- There is a stronger association for symbolic magnitude processing (i.e. number symbols) than non-symbolic magnitude processing (e.g. dot arrays).
- Symbolic and non-symbolic magnitude processing influence the development of each other.

MLD: Numerical magnitude processing difficulties are a core marker of MLD. Some mixed evidence of whether this is just symbolic magnitude processing or also non-symbolic magnitude processing.

# How is magnitude processing involved in maths?

Understanding the magnitude of numbers is important for many areas of maths:

- To give meaning to otherwise abstract words and symbols.
- To support estimation and spot incorrect answers.
- To identify part-whole relationships.
- To use place value with meaning.
- To build mental models of word problems.
- …

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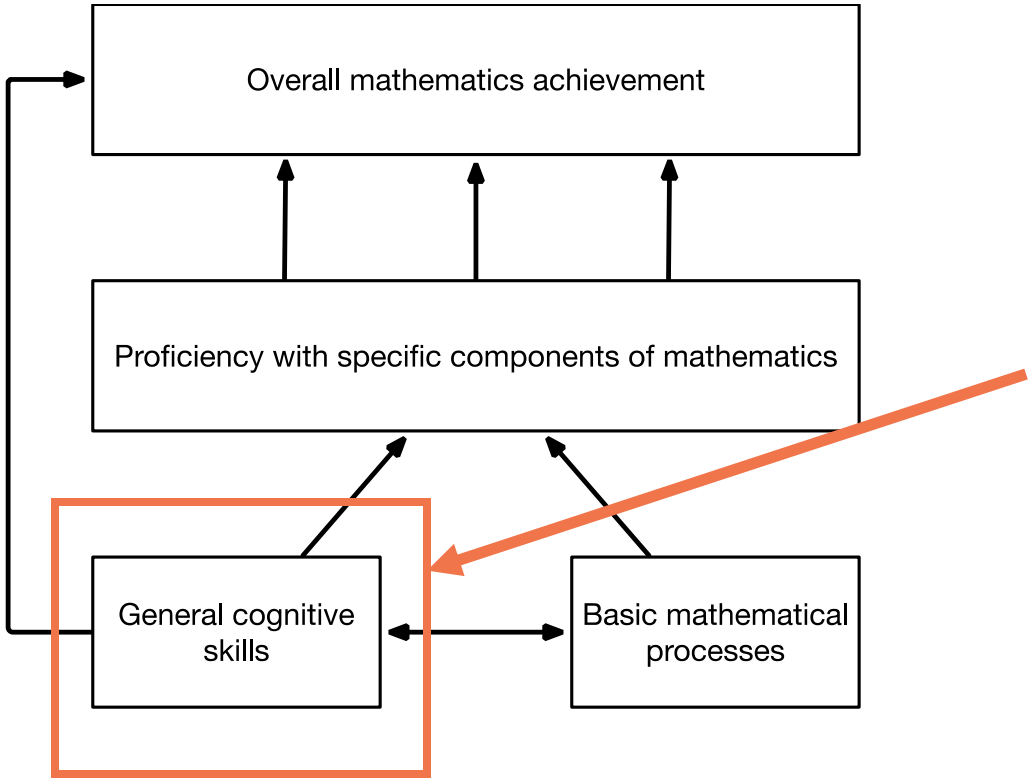
# Part 3: Mathematics draws on general cognitive skills.

# A framework for thinking about mathematics:




Executive functions (working memory, inhibitory control)

Spatial skills

Verbal ability

Motor skills

…

Gilmore, (2023)

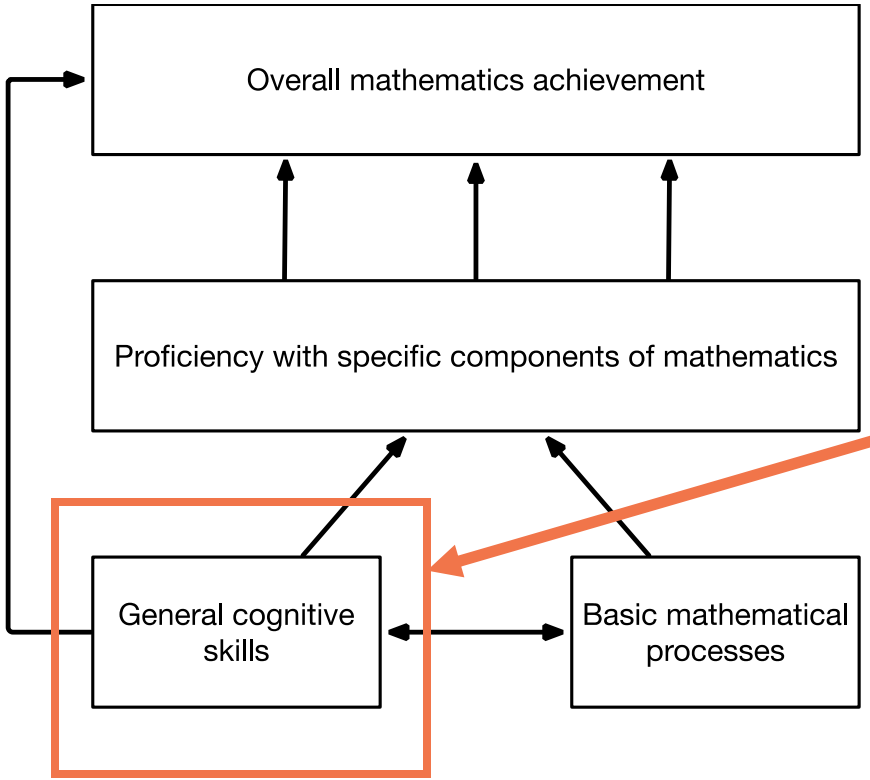
# Why consider general cognitive skills in relation to MLD?

1. Because we know that general cognitive skills relate to individual differences in mathematics more broadly.
2. There is wide heterogeneity among learners who struggle with mathematics.
   - A number of studies have investigated different clusters (Dowker, 2024*).
   - Where general cognitive skills have been measured, most studies find at least one cluster with general cognitive difficulties.



*Developmental Dyscalculia in Relation to Individual Differences in Mathematical Abilities

# A framework for thinking about mathematics:




Inhibitory control

Spatial skills

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# Inhibitory control

Involved when we need to ignore distracting information or suppress unwanted responses.

- There are individual differences in inhibitory control capacity
- Our inhibitory control capacity can vary from situation to situation.

Many studies find that individual differences in inhibitory control are associated with mathematics measures.

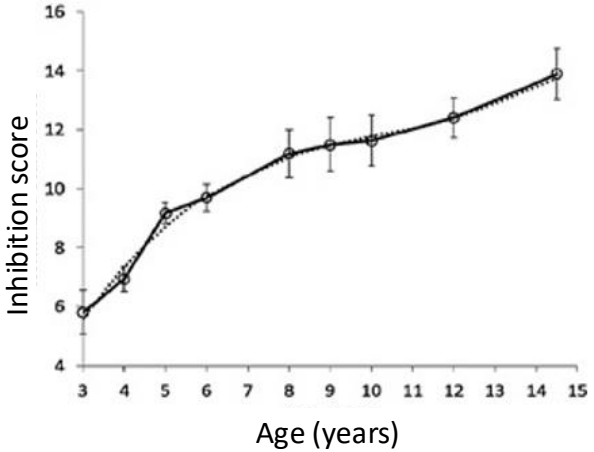
- From preschool to adults and across mathematical topics

MLD: Some studies find specific inhibition deficits, but this can depend on the inhibition measure used.

# How is inhibitory control involved in maths?

Ignoring distracting information.

- Distracting information can come from *our environment*.




*Zelazo et al. (2013)*

# How is inhibitory control involved in maths?

Ignoring distracting information.

- Distracting information can come from *the activities or tasks we are doing*.

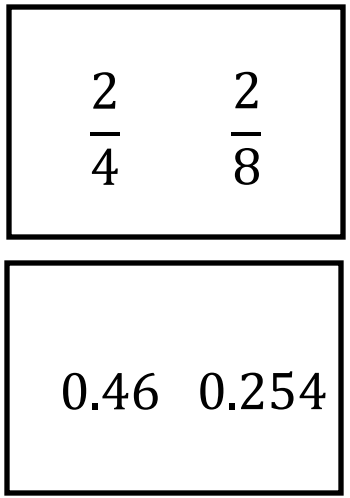
John had some books. He was given 3 more and at the end he had 8. How many did he have to start with?

Teams of 8 children are needed for a competition. 4 teachers arrange the children into 5 teams. How many children are there in total?

# How is inhibitory control involved in maths?

Ignoring distracting information.

- Distracting information can come from *our own prior knowledge*.



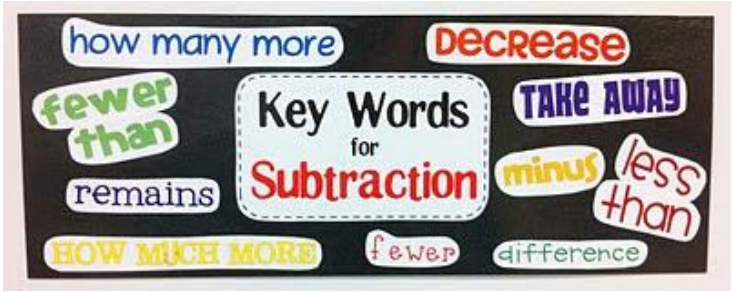

"…8 is bigger than 4 so 2/8 is bigger…"

"…longer numbers are larger so 0.254 is bigger…"

# Inhibitory control in the classroom

How can we support children's inhibitory control?

1. Recognise that children's inhibitory control is still developing.
2. Reduce unnecessary distractions (until learners are ready)
3. Give children time and opportunity to consider and discuss alternative strategies
4. Consider how the material or ideas being taught now might need to be inhibited in the future.



# Spatial skills

Involved in understanding the spatial properties of objects, such as their size and location, and to visualize objects and problems in the mind.

- Spatial skills develop throughout childhood.

Individual differences in spatial skills are associated with mathematics.

- Across mathematical topics: not just geometry but also arithmetic and number.

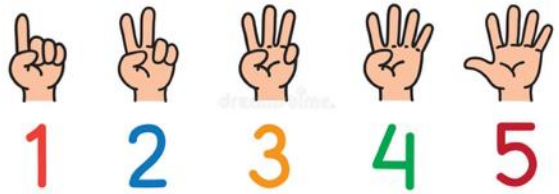
Spatial skills can be improved with training (e.g. block construction)

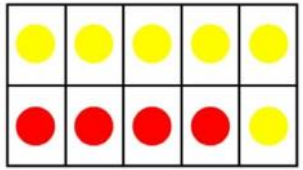
MLD: many studies of MLD don't consider spatial skills beyond VSWM. There is some evidence that number-space mappings may be impacted. But spatial skills may also be an area of relative strength for some.

# How are spatial skills involved in maths?

Spatial skills are important for all areas of maths, not just shape and geometry.

- Spatial representations of number



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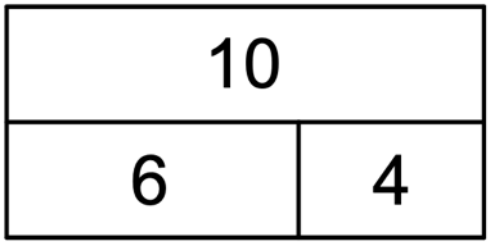
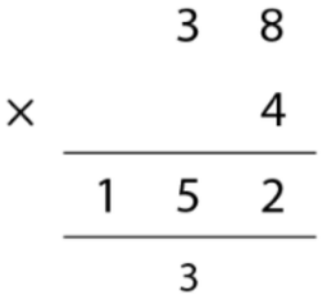
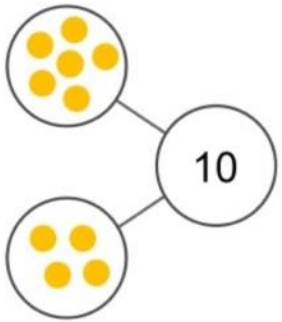
# How are spatial skills involved in maths?

Spatial skills are important for all areas of maths, not just shape and geometry.

- Spatial representations of number
- Spatially-based procedures



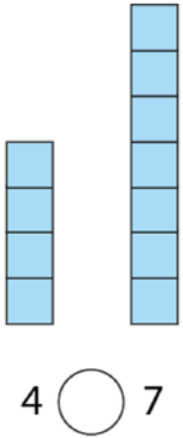



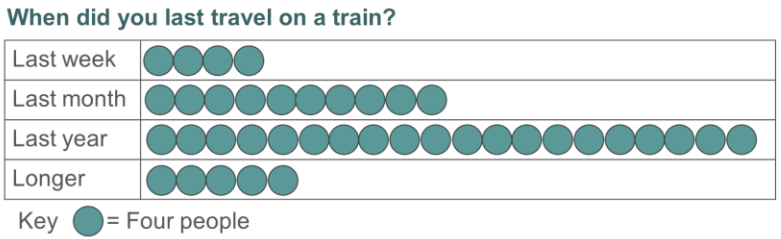
# How are spatial skills involved in maths?

Spatial skills are important for all areas of maths, not just shape and geometry.

- Spatial representations of number
- Spatially-based procedures
- Spatial information

| | Cheese (V) | Chicken | Falafel (V) |
|---|---|---|---|
| Cola | 20 | 36 | 17 |
| Juice | 12 | 27 | 15 |
| Water | 27 | 19 | 16 |

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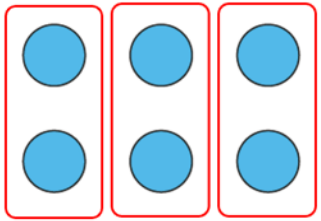
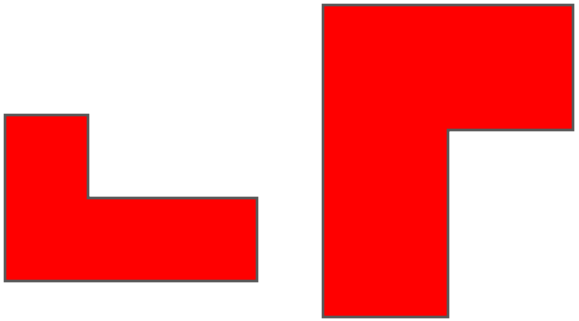
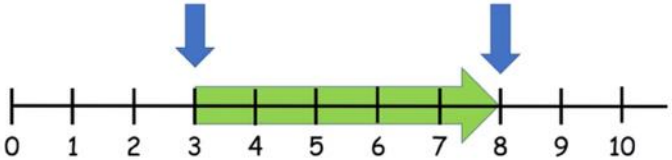
# How are spatial skills involved in maths?

Spatial skills are important for all areas of maths, not just shape and geometry.

- Spatial representations of number
- Spatially-based procedures
- Spatial information
- Mental visualisation





# Spatial skills and the classroom

How can we support and build on children's spatial skills in mathematics?

- Introduce visualization into problem solving: imagine a word problem or imagine changing perspective.
- Use spatial language and gesture.
- Use and explain visual representations.

Spatial strategies might be particularly helpful, and enjoyable, for children who struggle with numerical and abstract aspects of mathematics.

- Hands-on spatial activities that don't "feel like" maths.

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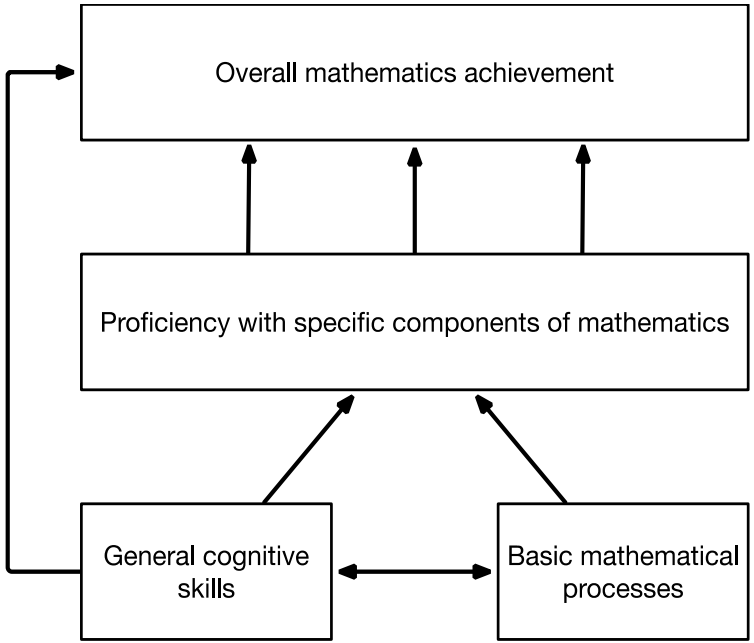
# Part 4: Learning happens within formal and informal learning environments

# Learning environments



# Formal and informal learning environments

Informal experiences from birth can influence the development of skills

- e.g. play experiences, mathematical and spatial language, positive attitudes.

Within education settings, understanding the cognitive demands of mathematical activities (and the mathematics itself) is important

- identify when to support and when to add challenge.
- isolated training of general cognitive skills is not effective

# Formal and informal learning environments

Regardless of heterogeneity, learners with MLD may benefit from the same approaches:

- Identifying strengths and weakness
- Building challenge slowly
- Using manipulatives and representations
- Supporting working memory and give time
- Don’t move to abstract symbols and problems too quickly

# Find out more

Open Access versions of all my papers available at: camillagilmore.wordpress.com

To find out more:

- ESRC Centre for Early Mathematics Learning see: www.ceml.ac.uk
- Working memory and inhibition see: www.sumproject.org.uk (with Lucy Cragg)
- Spatial reasoning: www.surrey.ac.uk/spatial-reasoning (with Emily Farran)