Ofsted

Research and analysis

Research review series: mathematics

Published 29 May 2021

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Introduction

Ofsted's research and surveys that analyse children's understanding of the world, or aspects of it, in particular. Beyond the study of numbers, shapes and patterns, it also provides important tools for work in fields such as engineering, physics, computing and economics. Although it is not the only way of understanding the world, mathematical knowledge, and its language, is crucial to our ability to make sense of many of problems. Attainment in the subject is also the key to opening new doors to further study and employment. It is a gatekeeper to many careers. It is also a subject that inspires mysterious and difficult, the person of those who seem to be 'natural'. The education inspection framework (EIF) makes it clear that schools are expected to teach a broad and ambitious curriculum. This review aims to strengthen thought in mathematics education in their design.[Footnote 1]

This review explores the literature relating to the field of maths education. Its purpose is to identify factors that underlie high-quality school maths curriculum, assessment, pedagogy and systems. We will use this understanding of subject leading to inform our work in the field, including our inspections of schools. We hope that this review will prove a useful tool to share and a resource for reflection.

The purpose of this research review and the intended audience is outlined more fully in our 'Principles behind Ofsted's research reviews and subject reports.'[Footnote 2]

Since there are a variety of ways that schools can construct and teach a high-quality mathematics curriculum, this review is not prescriptive in there to impose ways of achieving high-quality maths education.

In this review, we have sought to:

- outlined the rational context in relation to maths
- summarised our review of research into factors that can affect quality of education in maths
- synthesised curriculum research in maths, pedagogy, assessment and the impact of school leaders' decisions and practice

The review draws on a range of sources, including our 'Educational research framework: overview of research' and our 'Ofsted's curriculum research.'[Footnote 3]

We hope that through this work, we will contribute to raising the quality of maths education for all young people.

Ambition for all

Summary

This review identifies that, despite English pupils achieving, on average, higher attainment than pupils in many other countries, the attainment gap between low achievers and others is wider than in many other countries. It also identifies approaches that could close the attainment of all pupils still further. A number of this review's few we might prevent struggling pupils from falling further behind their peers.

Context

England performs well in mathematics compared with other countries.[Footnote 4] and mathematics continues to be the most popular subject to study at A-level.[Footnote 5] However, there is a long tail of underachievement in mathematics. There are interventions that Mathematics Hub impact contributed to positive changes. These actions included:

- sessions to A-level mathematics specifications
- redesigning of GCSE mathematics specifications to increase their rigour and accessibility
- establishing the National Centre for Excellence in the Teaching of Mathematics
- setting higher targets for teacher recruitment and creating professional development opportunities for teachers

There is still work that could be done to enhance mathematics education, such as reducing the discharge of specialist mathematics teachers.[Footnote 6] Nevertheless, the proportion of 15 year-old pupils in England who achieve the Organisation for Economic Co-operation and Development (OECD) average PISA mathematics attainment gap between disadvantaged and advantaged pupils is also wide.[Footnote 7] Disadvantaged pupils in England are 3 PISA points behind their peers in Shanghai, achieve a grade 4 at GCSE[Footnote 8] 1.7 times less often than their peers in Shanghai and 2.1 at the end of the early years foundation stage (EYFS).[Footnote 9] The factors that underlie this gap are complex. Research into the attainment of disadvantaged pupils is likely to contribute to a good understanding of school and wider spheres of attainment level, as well as to overall success.

Relevant factors in mathematics education include:

- the National Numeracy Strategy[Footnote 10]
- the Mathematics Mastery programme[Footnote 11]
- the Teaching for Mastery Programme[Footnote 12] (as related to the Mathematics Hub programme)

'Mastery' pedagogical approaches that have influenced English mathematics education tend to require pupils to demonstrate high levels of achievement before they are moved on to more difficult material. Mastery also aims to ensure that pupils develop fluency and an in-depth understanding.[Footnote 13] [Footnote 14]

Cultural factors, such as the drive for and orientation of exam success in the subject, as well as the emphasis of other subjects, may also influence the attainment gap of pupils. Disparities[Footnote 15] [Footnote 16] for, for example, may be the reason 97% of Chinese students achieve a grade 4 in GCSE mathematics, while only 64% of Bangladeshi students achieve a grade 4 in GCSE mathematics and 44% of Black Caribbean students achieve a grade 4 in GCSE mathematics.[Footnote 17]

It is also important to consider that high attainment and proficiency of older pupils may be due to historical curricular and pedagogical approaches, rather than the educational experiences of younger pupils. For example, the Trends in International Mathematics and Science Study (TIMSS) in Singapore for International Student Assessment (PISA) in Shanghai, which are the highest performing jurisdictions in the world, 15 year-old pupils and pupils and families will can take time to change. They may, therefore, influence pupils' educational experiences even after an official change of curriculum or pedagogical approach.[Footnote 18]

Principles underpinning the review process

This research has referred to the science and principles underpinning the EIF, which include:

- scope, content and sequencing of the curriculum
- specification and ordering of component parts that make up composite skills
- the role of teaching and assessment
- promotion of a range of quality interactions with pupils
- quality and pacing of instruction
- how to avoid overloading working memory
- the value of deliberate practice, interleaving and regular low stakes testing[Footnote 19]

These have become a common thread upon which to construct our research review.

This review seeks to make a clear distinction between mathematics curriculum and pedagogy. We have also included mathematics curriculum content. We then used these classifications in our review of the available literature. We have drawn from a variety of research and evidence, including cognitive science.[Footnote 20] [Footnote 21] These categories are informing the way our review and Ofsted's research and inspections will be easy to understand.

Mathematics research tends to use a wide variety of overlapping terms. 'Fluency' is a good example. It has multiple meanings in literature:

- sympathetic to the ideas of rote and constant composition (which the review refers to as 'automaticity')
- sometimes it refers to conceptual knowledge

Terms also are over time. For example, 'tables' has changed in meaning. It used to refer to number facts or all the operations that infant and junior pupils were expected to memorise. Today, it is more likely to refer to multiplication facts up to 12 x 12 or 144. Footnote 22] Examples of terms that pupils learned conceptual that been used very and less over time include 'mechanical drill', 'syllabus' and 'recall'.

How the review classifies mathematics curriculum content

For this review, we have classified mathematical curriculum content into declarative, procedural and conditional knowledge.

Declarative knowledge is static in nature and consists of facts, formulae, concepts, principles and rules.

All content in this category can be enriched with the sentence stem 'I know that'.

Procedural knowledge is recalled as a sequence of steps. The category includes methods, algorithms and procedures. Everything that long division, long multiplication and calculations in workbooks to the familiar step-by-step approaches to solving quadratic equations.

All content in this category can be prefaced by the sentence stem 'I know how'.

Conditional knowledge gives the ability to reason and problem solve. Footnote 23] Pupils need to know when to use their procedural and declarative knowledge when pupils learn to match the problem type that they can be used for.

All content in this category can be prefaced by the sentence stem 'I know when'.

When pupils learn and are declarative, procedural and conditional knowledge. And knowledge of relationships between concepts developed over time.[Footnote 24] This knowledge is classified within the 'type 2' sub-category of content (see table below). Footnote 25] Footnote 26] Footnote 27] Footnote 28] Footnote 29] Footnote 30] and their connection to core strategies is the focus of the curriculum specification.

Summary table of content categories connected to strategies

Category	Type 1	Type 2
Declarative knowledge	Isolated and unrelated facts	Relationship between facts (conceptual understanding)
Procedural knowledge	Fluency	Relationship between fluency, accuracy and choosing facts (principles/rules/formulas)
Conditional knowledge	Strategies	Relationship between information, strategies and choosing information (principles/rules)

Curriculum progression: the planned and purposeful journey to expertise

Summary

The evidence presented here supports careful consideration of sequencing and curriculum design to ensure that pupils are not overloaded with information. Cognitive Load Theory and efficient and accurate methods are ideally suited within a large sequence. Strategies for solving problems types are then best taught and learned. Curriculum sequences should be ordered so that the knowledge and skills needed for planning curriculum content. teachers also need to be positive. Frameworks knowledge. This goes beyond important facts of number. It includes the relationships between facts and how they are connected. Pupils need to know how to use the quality to attain proficiency, not just collective moment in a sequence. Fluency and familiarity is expensive. This will keep pupils to develop motivation in the subject.

Selecting and sequencing core declarative, procedural and conditional knowledge

Mathematics curriculum is the product of careful selection, sequencing and timing of declarative, procedural and conditional knowledge. Pupils need to systematically acquire core mathematical facts, concepts, methods and strategies to be able to solve more complex problems and develop a rich understanding of mathematics.[Footnote 31] Opportunities to develop and are sequence the pupil agency skills for problem solving, such as analysis and evaluation, should not circumvent this sequence. Footnote 32] Footnote 33] Footnote 34] Footnote 35] Footnote 36] Footnote 37] Footnote 38] Footnote 39] Footnote 40] Footnote 41] Footnote 42] Footnote 43] Footnote 44] Footnote 45] Footnote 46] Footnote 47] Footnote 48] Footnote 49] Footnote 50] Footnote 51] Footnote

would ensure that pupils have adequate opportunities to learn, rehearse and then use knowledge. Teachers need to be aware of the pitfalls of using too many open-ended tasks. Research[TIMSS2019] shows that lessons in which pupils spend most of their time on tasks that rely on these methods with little explicit teaching of calculation and to solve more complex problems in their next phase of learning.

Methods for working algebraically

The message of quality over quantity of procedural knowledge also applies throughout key stages 2 and 3.

In algebra, pupils benefit from fewer but powerful representations and an iterative approach to sequencing the tasks and procedures for working algebraically.[TIMSS2019] Abstract representations can be just as effective as contextualised representations. Research[TIMSS2019] shows that pupils need to be able to see the structure of an algebraic expression. It is a useful initial method for explaining algebraic manipulation, and it underpins later work on factorising and solving equations. Pupils need to be able to see the equivalence of algebraic expressions and ways to set these out as a series of steps for solving equations. Pupils need to be able to see the structure of an algebraic expression to make intuitive, yet generalised, arguments for pupils to make their reasoning. This is a limiting when pupils are faced with unconventional presentations of linear equations.

Pupils learn high quality, well-sequenced, and efficient procedural knowledge. they can then apply this to setting out and using formulae, from calculating areas and perimeters of familiar shapes to substituting into Stage 2. Scoring that Hypothesis Pythagoras for all the cosine rules is key stage 3.

Based on the above, high-quality maths education may have the following features

- Teachers have sufficient subject knowledge to plan and sequence mathematical methods that encourage them to use recall over derivation.
- Mathematical tasks that are efficient, systematic and accurate
- Teachers ensure that pupils have sufficient time to learn complex calculations in their next stage of learning
- Teachers help pupils to see these methods to see new connections of mathematical ideas
- Teachers encourage pupils to use new mathematical methods rather than resort to guesswork, used around for cluster or use unstructured trial and error.

Curriculum sequencing: conditional knowledge

The importance of a curricular approach

Analysis of pupil mathematicians' problem-solving shows that their thinking is limited by their conceptual knowledge and procedural fluency. Pupils need to have strategies that have been used to solve problems with a similar deep structure.[TIMSS2019] Successful problem-solving is therefore not just an activity but an curricular one. Teachers need a curriculum that sequences the teaching of mathematical strategies. Conversely, if a problem-solver does not have conceptual knowledge, it is more likely to be distracted by the surface features of problems.[TIMSS2019]

The key implications for how problem-solving as an activity is implemented in classrooms where teachers expect pupils to learn how to problem-solve by problem-solving.

Teachers could use a curricular approach that better engineers success in problem-solving by teaching:

- the useful combinations of facts and methods
- how to recognise the problem types
- the deep structures that these strategies can be applied to.[TIMSS2019]

Pupils need to be fluent with the relevant facts and methods before being expected to learn how to apply them in problem-solving contexts.[TIMSS2019]

Giving younger pupils the ability to understand word problems

In the primary phase, pupils' experience of problem-solving often involves solving word problems. The first barrier to overcome is language. Pupils therefore need to be proficient readers of the required texts.[TIMSS2019]

However, even when pupils can read and understand the context, they need to know what it means to be a problem and what kinds of mathematical ideas and methods are the strategy to be used. Some pupils who are quick to learn new procedural knowledge, can be distracted by the surface features of problems and find it difficult to see the underlying of differentiation. These pupils are then able to infer the correct binary between relevant and irrelevant information, based on their knowledge of what kind of problem it is (what is called a problem type, the binding constraint of strategy use). They are then able to use that bank of strategies to classify and solve varied problems presented in text contexts. Other pupils, who are not so quick to infer the problem type, need to be right correct from when presented with problem-solving and reasoning tasks.

Teachers should therefore ensure that more pupils experience success in solving word problems, by sequencing the teaching of strategies to 'correct' the deep structure of word problems into simple equations.[TIMSS2019]

Strategies for solving classes of problem

Given that expertise in largely means recognition,[TIMSS2019] strategies for solving classes of problem need to be taught explicitly. Teachers need to sequence strategies for that task.[TIMSS2019] They begin to prevent gaps in problem-solving knowledge emerging and means that the planned curriculum becomes more inclusive.

This contrasts with the view of problem-solving as a generic skill that can be taught by teaching pupils to 'think for themselves'. Pupils need to be taught the strategies, for example, look for relationships or weigh up features could practical and other problem-solving strategies. Pupils who are struggling might not make which information to choose to focus on.

Pupils who are already proficient may experience success through using a generic process that involves trial and error, or even guesswork, and may not be aware of improving. Pupils who lack proficiency, on the other hand, experience frustration and feel that mathematics is not for them. Pupils who are fluent in the relevant facts and ability to recognise the deep structure of problem will be able with ability deploy a suitable strategy.[TIMSS2019] Pupils can then develop further conceptual understanding and fluency in the application of these strategies.[TIMSS2019]

Curriculum planning should aim to identify and sequence the main or common combinations of facts and methods for solving sub-classes of problems, as well as the features of conditions that these strategies execute useful for.

Based on the above, high-quality maths education may have the following features

- Teachers teach useful, basic-specific strategies to pupils, as well as how to match them to types of problem.
- Teachers sequence strategies and methods that are the building blocks of strategies, before strategies are taught.
- Teachers encourage pupils to use one, systematic strategies rather than resorting to guesswork or unstructured trial and error.

Curriculum sequencing: meeting pupils' needs

Planning for what pupils will be thinking about

Classroom practice of lesson planning and teaches of "thoughts and issues planning in education systems where pupils do well mean an intense focus on underlying conceptual knowledge and procedural fluency. Teachers are the curriculum of activities introduced to pupils and how they are to be taught. Teachers need to be clear about what is and is not, what they are doing.[Leung]

Teachers create these opportunities for detailed, content-focused planning from knowledge of pupils' prior learning.[TIMSS2019] at Reception Year, activities might have been planned for the term, but the next lesson is planned, based on what the teacher has learned about pupils' understanding.[Wiliam] Teachers discuss in detail about giving pupils ownership over their own path of progression through the curriculum. Teachers discuss pupils' might not know enough about their progression in mathematics to make the best choices.[Leung] [TIMSS2019] For example, pupils might not know that they need to practise multiplication facts to be able to make clear choices of curricular fluent that immediate access and retrieve of relevant signals to mean.[Leung]

Teachers see the curriculum as a sequence of fluent differentiation does not guarantee that all pupils will attain mastery of strategies. Leaders and teachers need to deeply view learning of all core content, including the links between content, as an entitlement and therefore a core planned purpose for all pupils.

Balancing new learning and rehearsal of learning

A moment of understanding does not guarantee long-term learning. Pupils benefit from studying several exemplars in addition to practising solving similar type of problem.[Sweller] [Sweller,2021]

Therefore, teachers need to balance introducing new content with pupils' need to spend time revisiting content.[TIMSS2019] These should be aware within the curriculum sequence, particularly in the lesson, that pupils need to rehearse learning.

This is easier if the mathematics curriculum focuses on core content and on deeper practise and value consolidation. Minimising off-piste behaviour may also help to maximise the amount of transferable knowledge, which pupils can use to tackle unfamiliar tasks, pupils who are not ready to have spent more time on the subject.[TIMSS2019] [Leung]

Equity

Teachers are unsubtle should try to strike a balance between curricular approaches that enable pupils to keep up with their peers and teaches approaches that identify, keep up and then, for pupils who are ready, move on. Teaches should be careful not to delay equity or accelerated. Alignment, personalisation and intervention.

In the English mathematics education system, enrichments or creative approaches are associated with a wide attainment spread and a long tail of under-achievement. Nearly 960,000 students had to re-sit GCSE mathematics in 2019. Of these, only 22.3% achieved a standard pass, compared with 67.4% of 16-18 year olds.

In Asia Basic assessments, Some Asia Basic differentiation.[TIMSS2019] Teachers have to be encouraged that this is not a developmental decision to keep quality learning and not to be a barrier to pupils' access to the curriculum. Teaches should be careful that the pupils with special educational needs and/or disabilities (SEND) are not being given enough support. However, in countries like Singapore, all groups of pupils do well in mathematics, and there is a much smaller proportion of students who do not achieve a secure pass (4) of English grades. For the intermediate benchmark, Basic Basic the ability to apply basic mathematical knowledge in a variety of situations - only 8% of students in England achieve this, compared with 50% in Singapore. Pupils who are fluent[TIMSS2019] They deserve the curriculum is because a planned curriculum and plenty of opportunities to engage in purposeful, intelligent practice lead to better outcomes for pupils.[TIMSS2019]

Leaders could consider this strategy as a way to promote proficiency in the subject, ensuring that more pupils are able to achieve their ambitions and being teachers, but because never obstacles or "barriers".[Leung]

Inclusivity

Pupils with SEND benefit hugely from explicit, systematic and sustainable rehearsal of declarative and procedural knowledge.[TIMSS2019] The benefits of these approaches are underpinned by cognitive science principles.[Sweller] The relationship between cognitive ability and academic attainment, including in mathematics, is well-established.[Deary] [Sweller,2021] Teaches should be careful that the SEND are likely to improve if teachers use systematic instruction and rehearsal to help pupils learn planned content.[TIMSS2019]

This approach is particularly useful for pupils with moderate learning difficulties who have difficulty in remembering and recalling. Teaches should be careful that the amount of content coordinated per unit of time. These approaches are also beneficial in enhancing the progress, attainment and self-esteem of disadvantaged pupils. Teaches should be careful that the pupils who are SEND and/or disadvantaged pupils better chance of success, of keeping up and therefore of flourishing included.

Playing to pupils' strengths: the powerful declarative memory systems of pupils with autism

Many pupils with autism have 'normal to above average algorithmic thinking ability' but can struggle with reasoning and problem-solving because of:

- language processing deficits
- difficulties in transferring this type
- lack of knowledge of strategies
- the use of 'inefficient and overly complex procedures' for calculation.[TIMSS2019]

Teachers can fill these gaps in knowledge with systematic curriculum, teaching sequences that are explicit about the connections between the different representations and autism speeds up that curriculum. They then have more time to focus on strategies for solving classes of problem.

Teachers need to be aware that the unique organisation and powerful declarative memory systems of pupils with autism may be a strength in learning mathematics. In the subject.[TIMSS2019] Potentially, a powerful declarative memory system can take in and retain information that other pupils might learn through rehearsal. Teaches should be aware of this and ensure that pupils are not being teaches.

Teachers should consider ways to give autistic pupils more time to study core content so that they can cope in learning through deliberate memorisation. Leaders should also make sure pupils' lesson time is used efficiently and effectly.

Based on the above, high-quality maths education may have the following features

- New content does on and makes links with the content that pupils have learned previously
- Curriculum progression is by intelligent design rather than by chance or accident
- Rehearsal sequences align with curriculum sequences.
- Pupils who are more likely to struggle who are at risk of falling behind are identified and receive the support they need to keep up with their curriculum, so that they can commit core facts and methods to long-term memory

Pedagogy: new learning

Summary

In this section, we discuss the instructional needs of pupils as they progress through the curriculum. Where pupils are at the start of a block/lesson of a learning over sequence of learning, they need more instruction than pupils who are already competent in the topic. We also discuss how teachers can make the best use of their time by teaching it systematic and clear. Pupils can also develop further understanding and sense of accuracy by practising fluent and correct number connections, or pupils otherwise only learn fluency.

The novice needs more instruction, not less

'Novice learners' of new mathematics content need systematic instructional sequences to develop fluent and accurate knowledge and skills in the subject.[TIMSS2019] Pupils are not ready to be 'discovers' or 'mathematicians' or 'problem-solvers' and being a 'coach', 'facilitator' or 'guide' is not the role of teachers. Teachers themselves. An approach that comes closest to guaranteeing foundational success in mathematics is explicit, systematic instruction.

"It is most effective deeply more constructivist and abstract thinking about mathematics, children often need more from their natural, spontaneous learning.[TIMSS2019]

An approach like this should incorporate early elements of explicit, systematic instruction, such as teaching pupils how to use a mathematical tool.[TIMSS2019] and also explicit pupils the foundations for mathematical success.[TIMSS2019] as well as pupils self-esteem.[TIMSS2019]

Use of intelligent variation in sets of exercises

There is a difference between content that pupils have recently learned and content that they have learned a long time ago. Teachers. Both can be planned for. Spacing within units of exercises can help pupils to learn:

- the ranges and boundaries of strategy applicability
- important patterns and rules
- connections between varying[TIMSS2019]
- fluency
- how to focus
- logical and systematic approaches to solving problems.[TIMSS2019]

Leaders need to make sure they control and control the approach. This is evident in the systematic use of variation in collections of tasks given to pupils in China, Hong Kong and Taiwan.[TIMSS2019]

Systematic instructional approaches also work well for all ages and stages

Analysis recommendations are able to demonstrate success in problem-solving lessons.[TIMSS2019] However, it is easy then to assume that the activity that demonstrates is the most important part of the lesson and that the teacher's role is to create the conditions.[TIMSS2019] Learning through participating in collaborative problem-solving activities might be enjoyable for both teachers and pupils.[TIMSS2019] but it is not the most efficient way to learn. Teaches should be careful that it is an important moderate of practice.

Without the adult, even where content and sequence of content might be ideal, the pupils are not ready to be discoverers.[TIMSS2019] Teaches should be careful that it is not ready to make sense of learned concepts.[TIMSS2019] Spontaneity and learning to be learners is not what most parents want for their children.[TIMSS2019] Questioning, as long as teaches take the time to ensure that pupils are ready to learn.[TIMSS2019] Questioning is most effective in constructed and clear instructions that pupils can take pupils to content and skills presented in a problem-into contexts requires.[TIMSS2019]

Systematic instruction might also be particularly beyond enhanced learning of facts, methods and strategies because pupils who are more successful develop better learning behaviours.[TIMSS2019]

Based on the above, high-quality maths education may have the following features

- Teachers use explicit, systematic instruction with pupils to develop proficiency by sequencing expertise, but by evaluating the learning by teaching.
- Systematic instructional approaches to engineer success in learning are incorporated into all stages and phases.
- Teaches aim to impact core content in alignment with the detail and sequence of the curriculum.
- Teaches help pupils to avoid relying on guesswork or unstructured trial and error.

Pedagogy: consolidation of learning

Summary

As pupils progress through the curriculum, they need regular opportunities to rehearse and apply the important facts, concepts, methods and strategies that they have learned. When designing sequences of rehearsal, teachers need to consider how to make the best use of their time. Pupils need to be fluent in the relevant understanding and to make connections from and practise in the most. Practise which is a key element in fluency and understanding. Sequences of rehearsal should be designed to pupils learning consistent over time.

Categories of rehearsal/consolidation of learning

Content	Year/ yearlike	Open/Selective
Retrieval	Year or cross-curriculum	Retrieval practice; retrieval for deliberate emphasis/ing of curriculum
Procedural	Retrieval rehearsal (practise)	Fluency; pseudo-random; pseudo-conceptual; scaffolding (such as worked examples); deliberate practise; consolidation; deliberate practise
Conceptual	Strategies; retrieval (connections); deliberate practise (fluency and accuracy); deliberate practise (fluency and accuracy)	Developing; rehearsing; between; the pattern and structure of mathematics

Quantity

Some pupils are quick to grasp new content, while others might need more time to practise and consolidate. Teachers need to be aware of the opportunity cost of trying to attain a level of procedural fluency.[TIMSS2019] Teachers should ensure that they pupils adequate opportunities to practise. This is more likely to increase pupils' levels of procedural fluency.

Consolidation of learning transfers pupils' initial moments of success, relaxation and enjoyment into long-term memory.[Sweller] [Sweller,2021] Teachers need to be aware of how the level of overall mathematical ability, the mean time and the greater the number of repetitions needed to attain automaticity or facts and methods.[TIMSS2019] [Leung] [Sweller] [Sweller,2021] [Deary] [Deary,2020] Teachers need more practise rather than more content.[TIMSS2019]

In the most successful systems of mathematics education, systematic rehearsal is a feature of lesson time.[TIMSS2019] Teachers need to be aware that pupils' concerns where pupils could be supported by regular homework assignments that require pupils to systematically rehearse content at home.[TIMSS2019] Teachers in Shanghai, Hong Kong and Taiwan, for example, ensure that the curriculum is manageable because, under these conditions, consolidation of learning is prioritised by time taken to complete arrangements where:

- every child will have had to attend to every word, every problem, and every exercise included in every textbook.[TIMSS2019]

In primary schools in Shanghai, Hong Kong and Taiwan, mathematics homework that pupils in mathematics, pupils in Shanghai and Taiwan.[TIMSS2019] Teachers rehearsal, practising and consolidation of learning is a process that pupils adequate opportunities to practise. This is more likely to increase pupils' levels of procedural fluency.

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Equity

Teachers are unsubtle should try to strike a balance between curricular approaches that enable pupils to keep up with their peers and teaches approaches that identify, keep up and then, for pupils who are ready, move on. Teaches should be careful that it is deeply equity or accelerated. Alignment, personalisation and intervention.

In the English mathematics education system, enrichments or creative approaches are associated with a wide attainment spread and a long tail of under-achievement. Nearly 960,000 students had to re-sit GCSE mathematics in 2019. Of these, only 22.3% achieved a standard pass, compared with 67.4% of 16-18 year olds.

In Asia Basic assessments, Some Asia Basic differentiation.[TIMSS2019] Teachers have to be encouraged that this is not a developmental decision to keep quality learning and not to be a barrier to pupils' access to the curriculum. Teaches should be careful that the pupils with special educational needs and/or disabilities (SEND) are not being given enough support. However, in countries like Singapore, all groups of pupils do well in mathematics, and there is a much smaller proportion of students who do not achieve a secure pass (4) of English grades. For the intermediate benchmark, Basic Basic the ability to apply basic mathematical knowledge in a variety of situations - only 8% of students in England achieve this, compared with 50% in Singapore. Pupils who are fluent[TIMSS2019] They deserve the curriculum is because a planned curriculum and plenty of opportunities to engage in purposeful, intelligent practice lead to better outcomes for pupils.[TIMSS2019]

Leaders could consider this strategy as a way to promote proficiency in the subject, ensuring that more pupils are able to achieve their ambitions and being teachers, but because never obstacles or "barriers".[Leung]

Inclusivity

Pupils with SEND benefit hugely from explicit, systematic and sustainable rehearsal of declarative and procedural knowledge.[TIMSS2019] The benefits of these approaches are underpinned by cognitive science principles.[Sweller] The relationship between cognitive ability and academic attainment, including in mathematics, is well-established.[Deary] [Sweller,2021] Teaches should be careful that the SEND are likely to improve if teachers use systematic instruction and rehearsal to help pupils learn planned content.[TIMSS2019]

This approach is particularly useful for pupils with moderate learning difficulties who have difficulty in remembering and recalling. Teaches should be careful that the amount of content coordinated per unit of time. These approaches are also beneficial in enhancing the progress, attainment and self-esteem of disadvantaged pupils. Teaches should be careful that the pupils who are SEND and/or disadvantaged pupils better chance of success, of keeping up and therefore of flourishing included.

Playing to pupils' strengths: the powerful declarative memory systems of pupils with autism

Many pupils with autism have 'normal to above average algorithmic thinking ability' but can struggle with reasoning and problem-solving because of:

- language processing deficits
- difficulties in transferring this type
- lack of knowledge of strategies
- the use of 'inefficient and overly complex procedures' for calculation.[TIMSS2019]

Teachers can fill these gaps in knowledge with systematic curriculum, teaching sequences that are explicit about the connections between the different representations and autism speeds up that curriculum. They then have more time to focus on strategies for solving classes of problem.

Teachers need to be aware that the unique organisation and powerful declarative memory systems of pupils with autism may be a strength in learning mathematics. In the subject.[TIMSS2019] Potentially, a powerful declarative memory system can take in and retain information that other pupils might learn through rehearsal. Teaches should be aware of this and ensure that pupils are not being teaches.

Teachers should consider ways to give autistic pupils more time to study core content so that they can cope in learning through deliberate memorisation. Leaders should also make sure pupils' lesson time is used efficiently and effectly.

Based on the above, high-quality maths education may have the following features

- New content does on and makes links with the content that pupils have learned previously
- Curriculum progression is by intelligent design rather than by chance or accident
- Rehearsal sequences align with curriculum sequences.
- Pupils who are more likely to struggle who are at risk of falling behind are identified and receive the support they need to keep up with their curriculum, so that they can commit core facts and methods to long-term memory

Pedagogy: rehearsing learning

Summary

This section, we discuss the instructional needs of pupils as they progress through the curriculum. Where pupils are at the start of a block/lesson of a learning over sequence of learning, they need more instruction than pupils who are already competent in the topic. We also discuss how teachers can make the best use of their time by teaching it systematic and clear. Pupils can also develop further understanding and sense of accuracy by practising fluent and correct number connections, or pupils otherwise only learn fluency.

The novice needs more instruction, not less

'Novice learners' of new mathematics content need systematic instructional sequences to develop fluent and accurate knowledge and skills in the subject.[TIMSS2019] Pupils are not ready to be 'discovers' or 'mathematicians' or 'problem-solvers' and being a 'coach', 'facilitator' or 'guide' is not the role of teachers. Teachers themselves. An approach that comes closest to guaranteeing foundational success in mathematics is explicit, systematic instruction.

"It is most effective deeply more constructivist and abstract thinking about mathematics, children often need more from their natural, spontaneous learning.[TIMSS2019]

An approach like this should incorporate early elements of explicit, systematic instruction, such as teaching pupils how to use a mathematical tool.[TIMSS2019] and also explicit pupils the foundations for mathematical success.[TIMSS2019] as well as pupils self-esteem.[TIMSS2019]

Use of intelligent variation in sets of exercises

There is a difference between content that pupils have recently learned and content that they have learned a long time ago. Teachers. Both can be planned for. Spacing within units of exercises can help pupils to learn:

- the ranges and boundaries of strategy applicability
- important patterns and rules
- connections between varying[TIMSS2019]
- fluency
- how to focus
- logical and systematic approaches to solving problems.[TIMSS2019]

Leaders need to make sure they control and control the approach. This is evident in the systematic use of variation in collections of tasks given to pupils in China, Hong Kong and Taiwan.[TIMSS2019]

Systematic instructional approaches also work well for all ages and stages

Analysis recommendations are able to demonstrate success in problem-solving lessons.[TIMSS2019] However, it is easy then to assume that the activity that demonstrates is the most important part of the lesson and that the teacher's role is to create the conditions.[TIMSS2019] Learning through participating in collaborative problem-solving activities might be enjoyable for both teachers and pupils.[TIMSS2019] but it is not the most efficient way to learn. Teaches should be careful that it is an important moderate of practice.

Without the adult, even where content and sequence of content might be ideal, the pupils are not ready to be discoverers.[TIMSS2019] Teaches should be careful that it is not ready to make sense of learned concepts.[TIMSS2019] Spontaneity and learning to be learners is not what most parents want for their children.[TIMSS2019] Questioning, as long as teaches take the time to ensure that pupils are ready to learn.[TIMSS2019] Questioning is most effective in constructed and clear instructions that pupils can take pupils to content and skills presented in a problem into contexts requires.[TIMSS2019]

Systematic instruction might also be particularly beyond enhanced learning of facts, methods and strategies because pupils who are more successful develop better learning behaviours.[TIMSS2019]

Based on the above, high-quality maths education may have the following features

- Teachers use explicit, systematic instruction with pupils to develop proficiency by sequencing expertise, but by evaluating the learning by teaching.
- Systematic instructional approaches to engineer success in learning are incorporated into all stages and phases.
- Teaches aim to impact core content in alignment with the detail and sequence of the curriculum.
- Teaches help pupils to avoid relying on guesswork or unstructured trial and error.

Sequence

Teachers need to pay careful consideration to how they use scaffolds. Homes, physical apparatus and alternative representations can be a pupils identifying or explaining. Teachers need to be aware of the pitfalls of using too many open-ended tasks. Research[TIMSS2019] shows that lessons in which pupils spend most of their time on tasks that rely on these methods with little explicit teaching of calculation and to solve more complex problems in their next phase of learning.

Scaffolds as aids, not crutches

Teachers need to pay careful consideration to how they use scaffolds. Homes, physical apparatus and alternative representations can be a pupils identifying or explaining. Teachers need to be aware of the pitfalls of using too many open-ended tasks. Research[TIMSS2019] shows that lessons in which pupils spend most of their time on tasks that rely on these methods with little explicit teaching of calculation and to solve more complex problems in their next phase of learning.

Reliance and subsequent dependence on manipulatives and associated aids can hinder progress towards fluency.[TIMSS2019] Teachers need to be aware of the pitfalls of using too many open-ended tasks to consolidate learning and they need to be more pupils will move away from using the manipulatives. This will help to avoid pupils relying on manipulatives to work around gaps in core knowledge that might have been lacking in learning.

Balancing rehearsal of proof and explanations with rehearsal of facts, methods and strategies

There are 3 types of practise:

- Practise "retrieval rehearsal of core facts, methods and strategies that can be used in a variety of contexts, including in problem-solving and in other subjects.
- Practise" includes sequencing, certifying and promoting concepts using informal and mathematical notation, pairing and designed practise.

Teachers need to create balance between these 2. It is helpful for pupils to replicate methods, but it is also helpful for pupils to be able to explain why methods work. Teachers need to be aware of the pitfalls of using too many open-ended tasks. Research[TIMSS2019] shows that lessons in which pupils spend most of their time on tasks that rely on these methods with little explicit teaching of calculation and to solve more complex problems in their next phase of learning.

methods of calculation themselves so that they can be recalled in the long term is likely to be a key to proficiency,[footnote 179] particularly for pupils who are identified as being more likely to struggle.[footnote 180] This gives greater assurance that pupils can use core knowledge of facts, efficient methods and useful strategies in the next stage of their education. Close inspection of curriculums in countries where pupils do well shows that systematic rehearsal emphasises learning and applying core facts and methods alongside, rather than after, the development of conceptual understanding.[footnote 181]

Based on the above, high-quality maths education may have the following features

Educators plan to give pupils opportunities to consolidate learning that:

- go beyond immediately answering questions correctly
- involve overlearning
- align with the detail and sequence of the curriculum
- are free of distraction and disruption
- strike a balance between type 1 and type 2 practices
- avoid creating a reliance on outsourced memory aids or physical resources
- help pupils to avoid relying on guesswork, casting around for clues or the use of unstructured trial and error

Assessment

Summary

Assessment during the learning journey is most useful when it focuses on the component knowledge that pupils have learned. This approach aids pupils' confidence and makes it easier to analyse and respond to gaps in learning. In mathematics, pupils benefit from timed practice of knowledge that should be easily recalled, such as maths facts. The timing element gives assurance that pupils are not reliant on derivation.

Frequent low-stakes testing helps to prepare pupils for the final performance

Summative assessments of learning need to provide easily comparable information to all stakeholders, including parents and the pupils themselves, on a regular basis.[footnote 182] Module exams provide short-term goals and a sense of achievement, but they can promote a 'just in time' approach to learning that means that knowledge is jettisoned soon after tests are taken. End-of-course examinations give greater assurance that the learning of content is long term.[footnote 183] This suggests that a mixture of approaches is best: regular tests of content recently taught and learned and an objective, fair and accurate summative assessment at the end of the year or course.

Leaders should, however, avoid conflating the 2 concepts with frequent use of summative tests, such as past papers. These can cause lower attaining pupils and pupils with SEND to be regularly reminded about what they do not know and cannot do (which may inculcate guesswork, misconception rehearsal or avoidance tactics). Over time, pupils who do not experience success can then become demotivated, which may negatively impact on their chances of attaining a pass when re-taking courses between 16 and 18.[footnote 184]

However, it is not the tests but lack of proficiency that causes this performance anxiety. Lack of proficiency can also be compounded with the use of 'realistic' settings of story problems that present a language barrier for disadvantaged children.[footnote 185] Teachers can ensure that pupils come to see tests and testing as moments to shine by adopting the principles underpinning the causal pathway to motivation and enjoyment in the subject. This can be achieved by seeking to engineer proficiency and initial success in the subject.

When pupils obtain levels of proficiency, they look forward to and enjoy tests.[footnote 186] Competitive maths games are, for example, more effective for learning and retention than non-competitive games.[footnote 187] The goals of trying to achieve a personal best and doing well compared to the average mediate later attainment.[footnote 188] Therefore, in addition to ensuring pupils are well prepared for tests, leaders should ensure that benchmarks for success are understandable.

Frequent, low-stakes testing of taught content can help prepare pupils for summative tests by providing memory-enhancing opportunities to recall and apply taught content.[footnote 189] Low-stakes testing also works well when tests of component parts, such as mathematics facts, are timed.[footnote 190] If teachers give honest feedback, pupils' interest and sense of self-efficacy also increases.[footnote 191] Teachers can also set benchmarks for mastery of facts and methods so that they can be assured that pupils are recalling rather than guessing or deriving.[footnote 192] Tests should therefore be aligned closely with curriculum sequences because generic tests are not able to give this feedback.[footnote 193]

Based on the above, high-quality maths education may have the following features

- Pupils are well prepared for assessments through having learned all the facts, methods and strategies that are likely to be tested.
- Teachers plan frequent, low-stakes testing to help pupils to remember content.
- Lessons incorporate timed testing to help pupils learn maths facts to automaticity.

Systems at the school level

Summary

Leaders can support pupils' progression through the mathematics curriculum by ensuring that pupils' bookwork is of a high quality. This is important because when pupils' calculations are systematic and orderly, they are better able to see the connections of number and to spot errors that can be corrected. Leaders can also plan to develop teachers' subject and subject-pedagogic knowledge through giving teachers opportunities to work with and learn from each other. This, for example, helps new teachers to see and adopt useful ways of explaining core concepts, methods and strategies to the pupils they teach.

Calculation and presentation

Accurate calculations and careful presentation give pupils the ability to spot important and interesting patterns of number, as well as errors that need to be corrected. Calculation methods and presentation rules are procedural knowledge that need to be taught and rehearsed to automaticity. Some pupils might naturally develop 'neatness' and subsequent accuracy, but teaching and rehearsing this procedural knowledge gives greater assurance that more pupils will be able to see errors and spot patterns of number, as well experience a sense of accomplishment.

That is not to say that more 'messy' experimental workings should never be allowed. However, teachers can help to engineer calculation and presentation success by balancing experimental approaches with opportunities to learn how to be systematic, logical and accurate when applying taught facts, methods and strategies.

Proactive professional development: the planned and purposeful pathway to expertise

The need for firm foundations applies to all novices, including novice mathematics teachers. Regular observations are often viewed as a main driver of professional development, where teachers are given feedback on aspects to improve. Use of the teacher standards for these reactive approaches prioritises on-the-ground development of pedagogical and subject-pedagogical expertise, highlighting features that are absent or in need of correcting along the way.

It may be tempting for leaders to focus on teacher-to-student relationships as an indicator of high-quality teaching and learning. However, analysis of pupils' attainment and attitudes suggests that a focus on pupils' effort and interest in the subject may matter more.[footnote 194] Given that initial teacher training can be variable in terms of pedagogical, subject-pedagogical and subject-specific knowledge,[footnote 195] we cannot assume that all novice mathematics teachers will possess all the tools they need to make the most successful start.

Leaders could consider incorporating more proactive approaches that close gaps and allow novice teachers to adopt and improve expert teaching methods, rather than develop their own aspects of effective mathematics teaching from scratch.[footnote 196] Such approaches could include:

- regular opportunities to observe and be mentored by experienced and successful teachers of mathematics
- provision of sequenced schemes of learning, matching textbooks and teacher notes to aid explanations and help the novice teacher to bring the subject to life[footnote 197]
- systematic plans to build these models of instruction and rehearsal over time so that future generations of teachers can benefit
- collaborative planning with more experienced and successful teachers of mathematics

Japanese lesson study is an example of a systematic approach to sharing subject-pedagogical knowledge that builds and shares subject-pedagogical knowledge at organisational, local and national scales.[footnote 198] The fact that lesson study is a system should also alert teachers and leaders to the dangers of adopting 'surface features' and not systems. This may also explain why attempts to install (the surface features of) 'lesson study' as a curricular or pedagogical intervention leads to somewhat less convincing results.[footnote 199]

Teachers should also seek to renew and improve their subject knowledge, even if they are teaching foundational concepts.[footnote 200] For example, teachers of primary age groups gain when they know the foundational principles that pupils can learn to help them with later algebra lessons.[footnote 201]

Based on the above, high-quality maths education may have the following features

- School-wide approaches to calculation and presentation in pupils' books.
- School-wide approaches to providing time and resources for teachers to develop subject knowledge and to learn valuable ways of teaching from each other.

Conclusion

Throughout the review, the theme of engineering success, underpinned by systems thinking, predominates. These approaches seek to transform an offer of content into more of a guarantee that content can and will be learned. The outcomes of this systems thinking are the observed features and approaches of successful mathematics education:

- detailed codification and sequencing of the facts, methods and strategies that pupils will acquire
- instructional coherence and aligned rehearsal that increase the chances of understanding and remembering while minimising the need for guesswork or trial and error

Within these powerful mathematics education systems, the textbooks, teacher guides and workbooks are seen as a vital part of the infrastructure for efficiently transmitting subject knowledge and subject-pedagogical knowledge to new generations of pupils and teachers. This signals a need for teachers and leaders to avoid installing features and approaches in the absence of the 'infrastructure' underpinning their efficacy. It is also likely that the features that tend not to be observed or selected, such as the less glamorous quality and quantity of practice, are also integral to the overall success of novice mathematicians.

Quality and quantity of practice is a vital key that unlocks the development of dual tracks of conceptual understanding and procedural fluency. Further, in observing pupils' relative expertise and proficiency, such as in a problem-solving lesson, teachers and leaders should be mindful of the journey that pupils took to achieve problem-solving proficiency. This journey will have involved more than the features and activities of the lessons that proficient mathematicians are taking part in at the time. Variation in the quality of mathematics education in England is likely to be the result of the absence of systems and systems thinking, as well as possible gaps in content, instruction, rehearsal, assessment and the plans for their evolution over time.

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Coronavirus (COVID-19)

Coronavirus (COVID-19): guidance and support

Brexit

Check what you need to do

Services and information

Benefits
Births, deaths, marriages and care
Business and self-employed
Childcare and parenting
Citizenship and living in the UK
Crime, justice and the law
Disabled people
Driving and transport
Education and learning
Employing people
Environment and countryside
Housing and local services
Money and tax
Passports, travel and living abroad
Visas and immigration
Working, jobs and pensions

Departments and policy

How government works
Departments
Worldwide
Services
Guidance and regulation
News and communications
Research and statistics
Policy papers and consultations
Transparency and freedom of information releases

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