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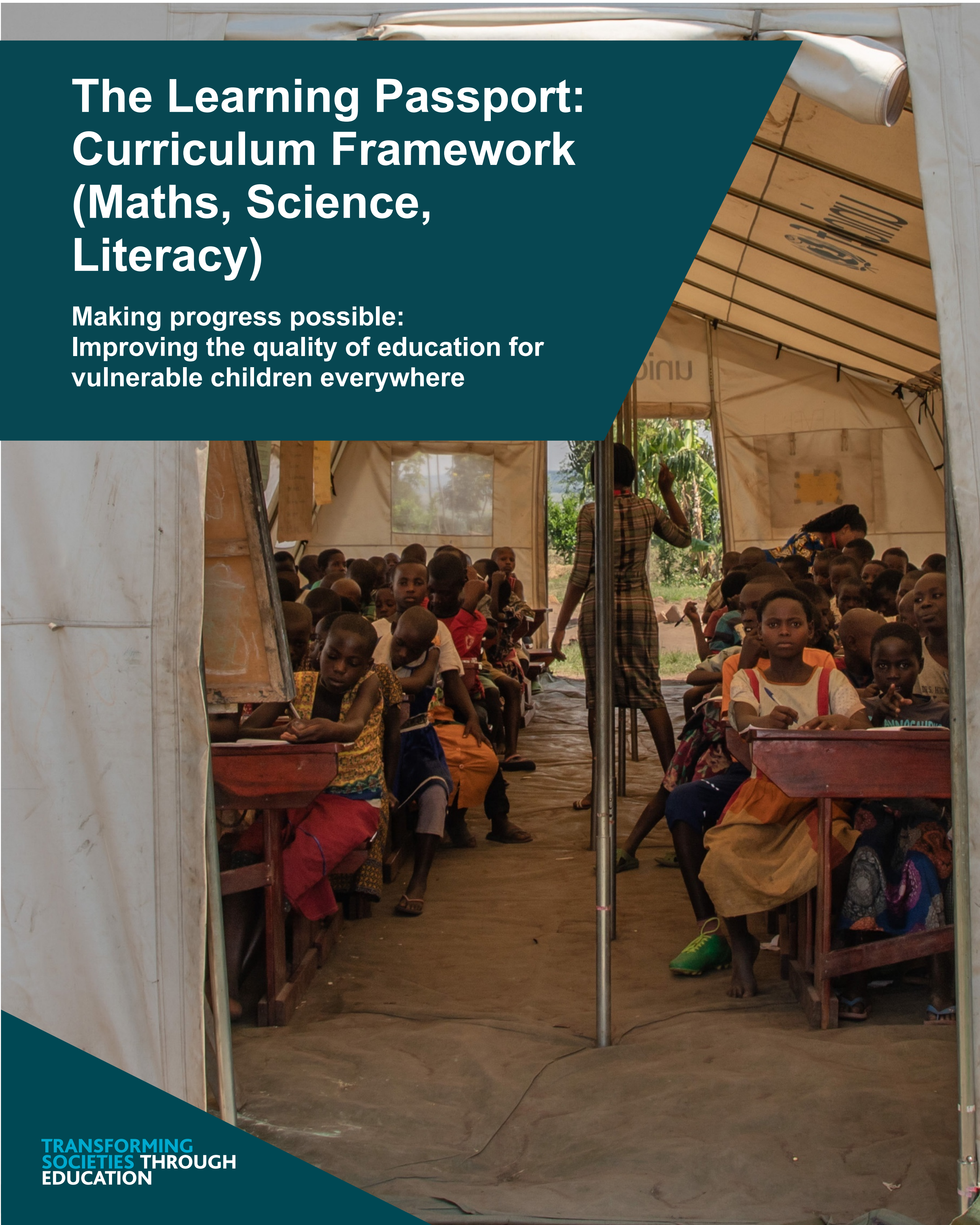
The Learning Passport: Curriculum Framework (Maths, Science, Literacy)

Making progress possible: Improving the quality of education for vulnerable children everywhere



TRANSFORMING SOCIETIES THROUGH EDUCATION

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Foreword by Tim Oates CBE

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The original specification for our curriculum work emphasised the importance of a clear statement of learning progressions in Maths, Science and Literacy, which could be used as a foundational reference point for the development of specific learning programmes and learning materials for displaced children. The learning progressions ('The Framework') would not aim to reproduce the breadth of content which are present in national curricula/national educational standards, since these progressions are not intended to provide a specific curriculum to replace the total experience of national curricula. Rather, the Framework provides essential development of a restricted but vital set of 'core' concepts, principles, fundamental operations (reading, writing, calculating) and core knowledge. This narrower focus may be seen by some to be reductivist, but in focusing on essential concepts (the particulate theory of matter, language about language, etc.) the Framework provides an essential 'bedrock' which can be further elaborated and supplemented if needed.

Learning programmes and materials derived from a distilled Framework of this kind can bolster the education of vulnerable children in difficult circumstances, and allow those who have missed out on essential steps to have their needs identified and their learning supplemented. The Framework avoids 'the never-ending spiral of specification' identified by Alison Wolf (1995, p.55), where over-detailed specifications cannot be held in the mind of young people and teachers, and thus fail to function as working reference points and benchmarks possessing genuine utility. Detailed interpretation for the purpose of managing learning experiences can be done through context-appropriate learning materials, learning support, and professional practice, where teachers or supportive others are available.

The meaning of 'curriculum' and the actuality of The Framework

Around the world, almost all nations have instruments which carry the label 'National Curriculum' or 'National Standards'. The latter is usually more accurate, since in almost all cases, the legal specification is not a detailed learning plan or set of detailed instructions for what should happen day by day in the classroom. Rather, they are statements of standards – things which children should achieve; usually stated in grade-by-grade progressions, some underpinned by evidence more than others. This is why the term 'curriculum' is misleading.

Following Schmidt, Wang and McKnight (2005) and Oates (2015), we hold the term 'Curriculum' should be retained but used as follows: for the reality of what children are learning in a specific set of circumstances (the learned curriculum); the overt and hidden elements of learning (formal and informal curriculum); the things which are assessed (the assessed curriculum); the things which have been taught and how (the enacted curriculum), and the legal or formal requirement (the stated curriculum). Here 'Curriculum' extends to less as well as more structured elements of learning programmes, as well as the work and thinking which children complete outside contact time. It extends to support and guidance, moral, social and emotional development, as well as cognitive development. This expansive understanding of 'curriculum' is essential for both understanding how education operates and for constructing robust and just learning programmes.

But, as mentioned, most things which are called 'National Curriculum' are lists of desirable goals. They are thus best described as 'National Standards'. They are no less important or helpful for being less expansive than a 'full curriculum'. In their carefully-devised parsimony and generality, they become short enough to be understandable and memorable as learning objectives. They allow appropriately variable implementation, meaning teachers can respond to the specific needs of particular groups of learners and individual learners. But at the same time they give structure and purpose to learning (focus), guide assessment (rigour) and structure progression. They promote alignment of instruction, materials, and content (coherence). These three qualities are essential for high quality learning (Schmidt, Wang & Curtis, 2005; Schmidt & Prawat, 2006; Schmidt & Burroughs, 2016).

It is these essential qualities which are supported by the Framework of outcomes which has been produced by the team and consultants at Cambridge Assessment. It is not an expansive set of learning programmes but something which is essential to their development, and it is specified at a level which is considered neither too general nor too specific. The Framework has been devised using state of the art research in learning progressions, on cognitive and human development, and fundamental elements of Science, Maths and Literacy. For example, the team has worked with researchers in science such as Jonathan Osbourne and Robin Millar who are at the forefront of international work on learning progressions.

During the framework development process our analyses indicated that the nature of progression in Literacy is of a different character to the progressions in both Maths and Science. This observation influenced the way that we structured the levels for the different subjects. In Maths and Science, the framework levels are not intended to be based on age and signify the development of concepts in sequence. By contrast, in Literacy the relation between that of language development and fundamental cognitive development requires that organisation of the sequence be according to age. We know that cognitive development is supported by and linked to the 'natural' processes of language acquisition at an early age. Missing out on elements of linguistic development – for example through lack of exposure to certain language forms, or by low levels of linguistic interaction – can affect cognitive development; and some of these things are age-related. Lack of early exposure and participation can mean that ages where ready, natural acquisition occurs are missed, require more formal, more protracted processes for later acquisition of these essential elements. This differentiates Literacy development from that of Maths and Science since the concepts in these areas are relatively age independent. For example, the age at which a learner should encounter the particulate theory of matter is not age sensitive in the same way. By using 'age levelling' to structure the Literacy framework we are recognising that age is an important factor in language development, and that learners should ideally aim to meet the age-related expectations. At the same time, we are also recognising that the framework provides a sequence for development if learners miss out on some stages and arrive at them later in their education. The framework presents an opportunity for identifying weaknesses in learners' Literacy development and this can help to focus the provision of opportunities to remediate any identifiable gaps in their development[1].

Although the Framework is unique, it has the following important aspects:

1. It is thoroughly research-based, using the extant literature in each area.
2. Where appropriate, it links to existing progressions in instruments such as PIRLS (international literacy survey) and Cambridge Maths (international maths framework).
3. It is informed by wide-ranging and systematic comparison of international curriculum/standards.

We consider the Framework to be unique and powerful, and highly valuable for the development of learning programmes, learning materials, and assessment for the world's displaced and vulnerable children.

[1] For more on this rationale and the difference with the Maths and Science frameworks see the commentary on pp. 116-117.

Contents

1 Glossary of terms

Adaptation Guidance: The supporting documentation that accompanies the framework and helps users to adapt it for their own situation (sometimes referred to as Contextualisation Guidance).

Adaptations: The contextualisation that will be made using the contextualisation/Adaptation Guidance.

Additional Language (L+): This refers to any languages which are not the learner's first language. We use the term Additional Language (L+).

Assessment: There is a distinction between assessment used for formative purposes and assessment used for summative purposes. We also recognise that these purposes need to be defined and an assessment system design needs to be considered in relation to how well it addresses these purposes. Assessment can be considered along a spectrum in this project. At one end of the spectrum the capture of a learner's responses to prompts and questions may be considered to have formative potential as it provides evidence to the learner and others about the concepts covered by a learner up to that point. At the other end of the spectrum there may be provision to summate and 'certify/accredit' a learner's achievement if certain conditions of the assessment system are assured (e.g. assessment tool quality; learner identity; parallel systems recognitions; assessment environment, etc.).

Accreditation: The process leading to the certification of achievement of prior learning or formal recognition of prior learning. The quality assurance process evaluating and verifying the services and operation of institutions or programs by an external body to determine whether recognised standards are fulfilled.

Blueprint: A broad outline that covers the minimum requirements of the programme if it is to achieve our desired aims. The details are context-agnostic/independent. This may be synonymous with 'Framework'.

Competences: Competence is a holistic conception. It involves the integration of several components, including the mobilising of context appropriate knowledge, skills, and psychosocial resources (including attitudes) to achieve a purpose driven task.

Components: The organisational elements of the learning framework that make up a learning sequence or progression. The subject domains (Maths, Literacy, Science, Social and Emotional Learning). The subject domains (Maths, Literacy, Science, Social and Emotional Learning) are made up of various components (contingent concepts, principles, fundamentals operations and core knowledge).

Context-agnostic: The sequences that are included in the framework are designed to be independent of any particular situation. Their validity is based on the way that they link to each other (they provide a foundation for subsequent learning). This links to the concept of 'powerful knowledge' (Young, 2014). The Maths, Literacy, Science and Social and Emotional Learning sequences must be based on knowledge and concepts that are contextually-agnostic.

Control factors: Control factors are a framework of factors (such as curriculum content, pedagogy, governance) with which policy can engage in a strategy to improved education. Those who change one or more control factor(s) need to be mindful of how arrangements align and interact across control factors and the educations system. www.cambridgeassessment.org.uk/Images/cambridge-approach-to-improving-education.pdf

Contextualisation Guidance: The supporting documentation that accompanies the framework and helps users to adapt it for their own situation (sometimes referred to as Adaptation Guidance).

Curriculum: This is a learning programme; it includes both enacted and intended elements and includes formal and informal learning opportunities. A curriculum framework provides the academic/disciplinary basis for local and regional curricula that will be created by local/regional specialists.

Curriculum coherence: An indication of the extent to which the curriculum aims and content, as well as textbooks, teaching methods, and assessment are all aligned and reinforce one another. Some research findings suggest that a high level of curriculum coherence is associated with high performing systems. For this project the term is also used to refer to maximising the extent to which the Maths, Science, Literacy and SEL each support learning in each of the other mentioned subjects.

Curriculum map(ping): A curriculum map is a visualisation of relationships within and between a curriculum or curricula, for instance, charts, diagrams and so on. Curriculum mapping refers to a variety of methods for creating and using the curriculum maps. This is a component of the methodology that empirically grounds the development of the curriculum framework.

Curriculum Framework: A broad outline that covers the minimum requirements (learning concepts, ideas, principles) that can structure curriculum design. These details are context-agnostic/independent.

First Language (L1): This refers to the language learned in the home. Children may have more than one first language. We use the term First Language (L1).

Language of instruction (LOI): This refers to the language medium in which education is being delivered. In our project this refers to the language in which Maths and Science are being taught. Literacy will be in the same language as the medium of instruction used for Maths and Science. We use the term LOI.

Learner profiles: These are created to consider potential learner characteristics during the planning and development phase. These include various characteristics (such as age, level of prior knowledge, etc.) that need to be taken into account when the framework is adapted for local contexts.

Learning Progressions (see also Learning Sequence): These are the contingent concepts, principles, fundamentals operations and core knowledge that learners need to accrue through their education. They are successive and based on key waypoints (see definition below). For some in education, 'progression' refers to a sequence that uses a specific formula and has only one correct and definite sequence. The framework aims to include sequences of the key disciplinary knowledge for Maths, Science and Literacy. This sequence involves the movement across waypoints that have potentially multiple routes. We are trying to establish the most efficient routes through these waypoints (i.e. that include the fewest/most important concepts etc.

Learning Sequence (see also Learning Progressions): Refers to an order that is based on logical rules and may have some variance. This is a preferred term for some educationalists who define ‘Learning Progressions’ as a specific formula that has only one correct and definite sequence.

Level: This is a way of grouping the learning waypoints into manageable clusters across the frameworks. For Maths and Science these levels are not intended to be based on age. The Literacy framework is structured around age-related targets.

Literacy for Access: The minimum core Literacy competencies required to access learning (including but not limited to accessing the Maths and Science curriculum framework in this programme).

Pathways: The routes through a learning sequence. They are structured around waypoints. There are multiple potential routes from one concept to another. The framework tries to identify the optimal route through a learning sequence for each subject domain.

Pedagogy: In A Cambridge Approach to Improving Education pedagogy is a Control Factor. It includes “teaching and learning approaches; implicit and explicit theory driving teaching and learning; didactics; models of ability; models of progression; setting and streaming; classroom culture; homework and practice models” (Oates, 2017, p.20).

Pilot: A testing of the framework in order to see initial implications, areas needing revision, etc. before widespread implementation.

Touchpoints: The knowledge, skills and understanding from multiple curricula (usually from different countries) which are shared, aligned or equivalent. The touchpoints are generally found through a curriculum mapping exercise.

Waypoint: The components of a learning sequence pathway that link with prior and subsequent components, within or across subject areas.

2 Project outline and methodology

The Learning Passport project is part of a joint collaborative project that involves UNICEF[2] and the University of Cambridge based around a Programme Cooperation Agreement (PCA) between Cambridge University Press and UNICEF signed in April 2019. The goal of the project is to develop a blueprint curriculum framework as a basis for programme and materials design, with these to be used with refugee and displaced learners ('learners on the move') in Education in Emergency (EiE) contexts[3].

This report outlines the methodology that was used to explore the development of the curriculum framework and includes the output frameworks and matrices that resulted from the development process. In Cambridge the framework development project involved several departments and collaborative partnership organisations from across the University. These partners included Cambridge Assessment, Cambridge Mathematics, Cambridge University Press, the Faculty of Education, and the Department of Psychology.

Discussions prior to the PCA signing established several conditions that would shape the framework. Foremost amongst these was the idea that the framework would focus on "basic education and core skills", and that this would include "basic Numeracy, Literacy, Science and Social and Emotional Learning" (UNICEF, 2019, p. 2). This idea influenced us to focus on the elementary, or primary, education phase (which we interpreted as being relevant to learners approximately around the ages of 5-14[4]). Finally, it was established that the Social and Emotional Learning (SEL) component of the framework (Boyd-MacMillan & DeMarinis, 2020) would be developed by the Department of Psychology at the University of Cambridge, whilst the curriculum framework for Numeracy (Maths), Science, and Literacy would be developed by the Education and Curriculum Group in Cambridge Assessment's Research Division (ARD).

For our development we interpreted the notion of a *framework* in a particular way. What we set out to produce was a clear and parsimonious statement of a set of essential learning goals, in a clear progressive sequence. We would not see these sequenced goals in themselves as a learning programme, since such a programme requires contextualisation and learning materials which elaborate learning activities (e.g. explanations, activities, etc.). These sequenced goals are the essential basis for high quality learning materials which support autodidact and supported learning. The sequences are essential, since they list clearly the learning goals which are vital in a specific subject. Therefore, our framework would be based around a list of key concepts, principles, fundamental operations, and core knowledge. The correct, developmental arrangement of these components could then enable the production of high-quality contextualised materials and exciting, engaging learning activities.

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[2] UNICEF is the United Nations Children's Fund. Its mission is to advocate for the protection of children's rights, to help meet their basic needs, and to expand their opportunities to reach their full potential.

[3] In this report we choose not to use 'blueprint' to describe our framework. The term was originally used in early project discussions to highlight the way that a curriculum framework is a preliminary stage in the development of a more fully formed curriculum.

[4] In some systems the secondary education phase begins around age 14 (e.g. Pakistan, South Africa).

Our work was predicated on contemporary curriculum thinking at Cambridge Assessment (Oates, 2017) which foregrounded the importance of two key principles for framework development: *learning sequencing* and *parsimony*. The first of these principles suggests that a framework should be structured around learning sequences, sometimes referred to as *progressions* (although this is a contested term), and this is a developing area. Traditionally, learning sequences have tended to be a product of general consensus around the accepted sequence of teaching in specific jurisdictions. Although it is possible that such traditions may tap deeply into an intuitive organisation of learning, which may be important for the development of human cognition, the field has been greatly enhanced by research work on cognition and conceptual sequencing. Complex, fundamental concepts have been pushed down to earlier ages in some instances, the dependent sequences between concepts have been explored, and the empirical base of sequences enhanced. This work has not informed many of the national curricula/national standards around the world, and we felt that it was important that we could draw on this work for our framework development.

The second principle, parsimony, suggests that a framework should be based around the stipulation of a judicious selection of content. This parsimony allows a relatively small number of concepts of key importance to be explored in great depth. The work of Schmidt and colleagues on international educational performance (Schmidt & Prawat, 2006; Schmidt, Wang, & McKnight, 2005) suggests that focus, rigour, and coherence are vital to the organisation of successful educational systems. Curriculum frameworks can add focus to the curriculum design process by including a parsimonious list of key subject content. The often compressed learning time and opportunity for displaced learners makes it important to capture and articulate the fundamentals of key subjects, and to avoid the elaborate and broad curriculum models which are possible in stable and more regular learning contexts. An overloaded curriculum framework tends to lead to enforced local decision making about priorities, poor teaching and learning, and opening of gaps between pupil groups. The idea of our curriculum framework was not to deliver something which was impoverished, but something which was rich and essential. This mirrors the *fewer things in greater depth* principle, which is at the heart of the best systems around the world. This equips learners with the ideas and content which provide a foundation for progression through to the highest levels of attainment.

This report outlines the general approach that we adopted in developing a curriculum framework. The conditions relating to learners on the move vary greatly and can be fragmented (Cambridge Education, 2017), with emergency responses often possessing some of the complex and uncertain characteristics of a *wildfire activity* (Engeström, 2009). Such responses often involve highly motivated participants who, despite having a decentralised organisational structure, require rapid coordination. These responses also tend to have high levels of resource demand (in terms of finance, time, and energy). It has been observed elsewhere that multi agency working is often marked by diverse and competing challenges (Devitt & Borodzicz, 2008), and this adds another layer of complexity to responses in EiE contexts. For us, the clear challenges around forging a high-quality educational response in EiE contexts reinforced the need to establish a coherent curriculum framework that could support effective processes. In other words, a framework that articulated important learning concepts as well as the potential pathways through these concepts for learners could be an effective tool for coordinating scarce educational resources (e.g. teaching time, learning materials etc.).

Another challenging condition around the framework development process included its relationship with the Research and Recommendations Report (Cambridge University Press & Cambridge Assessment, 2020), which was a project deliverable that was intended to inform the curriculum framework design, and was drafted in parallel with the framework. We ensured that we worked closely with the Research and Recommendations Report authors throughout, but there were areas of framework development that necessarily preceded the completion of the report. This meant that the framework designers were drawing on expertise and literature that may not have been available to the report authors.

2.1 Curriculum framework design stages

From the outset, our approach to design was exploratory, reflecting the specific contextual parameters and challenges of generating a globally relevant but context-agnostic framework in the three different subject areas. This exploratory development feature also meant that the design evolution across each subject had the potential to vary, as each sought to meet the design requirements in terms of the specific logic of the respective subject. Our design process evolved over the timeline of the project, and we present our narrative of this development process in the order in which it occurred. This allows us to explain how decisions at one stage of the process influenced later ones.

For this development we engaged with a diverse group of key experts from across the fields of Maths, Science and Literacy education (see Appendix 1). These experts invested a great deal of effort engaging with the novel challenges presented by the framework development project, and the outcomes reflect the quality of the combined expertise of this expert group.

In establishing our approach to the development of the curriculum framework we needed to establish a strategy for navigating our way through the uncertain space that characterises EiE contexts (Johnson, Coleman, & Fitzsimons, 2019). In this section of the report we outline the overarching stages of development that we went through for each of the subject frameworks. We then explain the particularities of each subject development through each of these stages, along with the reasons for the variations that can be observed across the respective subjects.

At the initial stage of the development there were many unanswered (and perhaps unanswerable) questions which we needed to work around. These included questions of who would the learners be, who would facilitate, teach, coordinate, and adapt the enacted curriculum; what should be taught, what resources would be available, what learning spaces would be used; and, where would the learners be and where were they likely to move to (both geographically and as learners). One assumption that we incorporated into our thinking at a very early stage was that we should write for those that find themselves in the worst situation, isolated, insecure, and unsupported in any real way, and certainly not in anything approaching formal education.

To navigate around these many uncertainties, and to impose order on the development, we worked through three development stages for each subject:

Stage 1: Process of defining the subject framework principles and parameters

Stage 2: Generating the subject framework descriptors

Stage 3: Establishing intra-subject coherence

In short, these stages provided the common ground upon which we could coordinate the work of researchers and consultants towards achieving our shared aim of developing a high-quality curriculum framework. The final stage of the development involved establishing inter-subject coherence. As this stage involves the consideration of all subjects, it is described in a stand-alone section of the paper.

Prior to the first development stage, we needed to engage in reflective discussions to establish the key principles that we thought should underpin the curriculum framework. This discussion was informed by our recent thinking around which principles should underpin curriculum framework design (Oates, Johnson, & Coleman, 2019). This thinking conceptualises framework design around three interacting levels of *curriculum framework content*, *pedagogy and resources*, and *broad curriculum issues* (Table 1).

Table 1: Principles underpinning framework design

Content	Sound and clear sequences Foundational elements Avoid contradictions Avoid overload Reading with facility
Pedagogy and resources	Space for practice Variance in presentation Access to complex language
Broad curriculum issues	Curriculum location (local and national)

By engaging in exploratory discussions around these design principles we were able to consider whether there should be a hierarchy of principles in relation to our project context, and the potential impact of such principles on learning.

The outcome of our discussions around the principles that informed our framework development is shown in Table 2. By attending to our most important priorities we were able to start to shape the emerging curriculum framework in relation to the demands of the original project brief.

Table 2: Key principles that informed our framework development

		PRINCIPLE → → →	PRACTICE
HIERARCHY OF PRIORITIES		Criterion	Practical implications
	1	Needs to support progress in the subject area for all learners (quality).	Integrating conceptual and enquiry dimensions.
	2	Needs to support potential re-integration of all learners (comparative).	Have a clear record of what has been covered. Content needs a universal quality.
	3	Depth over breadth. Ensuring time is used to move learners forward with key building blocks.	Focus on depth, so will steer clear from the more detailed frameworks.
	4	Needs to be as context-agnostic as possible	The concepts and knowledge need to be abstract in nature, so that they can be applied in a variety of contexts.
	5	Cannot rely on learning resource availability.	Focus on skill development as opposed to action with specific things (generalisation).
	6	Cannot rely on specialist teacher knowledge or guidance.	There needs to be clarity in language and terminology used.
	7	Should support social interaction/some grouping (to support inter-personal element, co-learning and 'streamlining' of some teacher instruction)	Groupings of 2 or 3 levels together in the enquiry. Thematic approach (underpinned by clear conceptual sequences) will allow different learners to work together on the same theme, but on different objectives.
	8	Potential for assessment of/for learning.	If it is clearly articulated and separated into stages, then it can be assessed.

At the top level of the hierarchy we placed the need for the framework to support learning progress, as this was at the heart of the requirement to 'support high quality learning', and was an important component of the project design. We also wanted the framework to support the transition of learners to other learning systems, as the notion of transfer was also a central aim of the project. Finally, we wanted to support efficient learning (and minimise the effects of 'wildfire activity') through ensuring that the most important elements of learning were used to structure the framework.

It is clear that some of the principles relate more specifically to implementation and could not be dealt with directly through the curriculum framework itself. By outlining these principles, we wanted to ensure that they would not be precluded from being met in the future implementation stages. For example, we anticipated that autodidactic learning, as a concept, may be important. Given the range of learning contexts in which children find themselves (isolated and alone right through to able to attend formal school settings with teacher support) we felt that in science and maths we should aim to specify content and design materials which supported autodidact learning. Materials designed for this would be equally useful in contexts supported by qualified teachers, while the reverse would not be true. Having said this, there is scant research on autodidact approaches with very young children, or those with substantial depression or problems in educational attainment. While autodidact approaches may be possible in respect of science and maths, we are very hesitant to suggest that such approaches could be used in the acquisition of literacy, since learning to speak is an inherently social process, needing adults and peers to support language acquisition. Therefore, we ensured that our development did not encompass content that precluded autodidactic learning issues in Maths and Science, and this should be explored at later stages of the project.

Taken together, these principles suggested that we needed to focus on framework content that was contextually-agnostic (or in some way 'universal') in character, and that was sequenced in a logical and efficient way. In addition to considerations about the character of the framework content, consideration of EiE contexts also raised some pragmatic considerations that we wanted to attend to as a conscious design feature. It was anticipated that by including a relatively parsimonious number of core content areas in the framework we would allow room for important localised, pedagogic contextualisation. This would help to attend to concerns that overburdened and decontextualized frameworks lead to variances across different contexts as unconstrained 'local' choice and prioritisation takes place (Oates, 2011; Reynolds & Farrell, 1996; Shuayb & O'Donnell, 2008).

2.1.1 Stage 1: Process of defining the subject framework principles and parameters

Our key principles (Table 2) led us to focus on the idea of how we could identify and include learning content that had universal characteristics (i.e. that was context-agnostic). This idea was crucial because it would allow us to organise our framework around content that not only linked across different learning areas, but that was also able to link across learning contexts and support transfer across systems. In other words, we wanted content that was intra-subject in nature (e.g. that connected mathematical and scientific concepts), as well as being relevant across individual regional and/or national learning contexts. For us, this had clear implications for the methodological approach that we needed to use for the framework development.

Our earlier thinking on curriculum principles had outlined to us the importance of including content that conveyed something of the *foundational elements* of a subject area. We articulated these elements as being the core concepts, key principles, fundamental operations, and core knowledge of a subject area (Oates et al., 2019). Elsewhere there have been discussions that look to establish links between these foundational elements and the notion of Powerful Knowledge (e.g. Burns, 2018; Maude, 2018). The intersection between these two areas of thought centres on the extent to which foundational elements of knowledge may not be obvious to learners through their everyday experience, since a key characteristic of Powerful Knowledge is that it can be counter-intuitive (Rata, 2019; Young & Muller, 2013). This means that access to this knowledge requires mediation to a learner through another person or through access to others' idea via resources (such as texts).

As part of our thinking in this development we engaged with recent debates around Powerful Knowledge as there appeared to be overlaps between these debates and the ambitions of our development to support educational access, social justice, and learning transfer.

With regards to educational access, Powerful Knowledge is a form of knowledge that is independent of contextual factors and, since it is not dependent on a learner's home experience, it 'takes them beyond their own experiences' (Young, Lambert, Roberts, & Roberts, 2014, p. 7). The Powerful Knowledge argument can be extended to propose that education enables social mobility through allowing all learners access to important knowledge that provides 'the opportunities to succeed in life' (Burns, 2018). The reason for the enhanced social mobility potential that relates to Powerful Knowledge, according to Young & Muller (2013), lies in its high abstraction and generalization potential so that it transfers between contexts.

With regards to social justice, we considered the potential importance of linking our framework with Powerful Knowledge because we argue that having access to important knowledge is a universal right for all learners regardless of background or social standing. This points to the social justice potential of knowledge and curriculum development since access to 'the knowledge of the powerful' (Young, 2014) for all learners helps to counter the encultured disadvantages that some learners have as a consequence of their background. Although there is debate about the extent to which school can compensate for enculturation (Jameson, 2016), it can be argued that access to knowledge potentially allows marginalised learners to use it as a resource for cognitive development. At the same time, the potentially negative effects of restricted access to knowledge on the development of marginalised learners has been noted in a variety of contexts (e.g., Abadzi, 2006; Wheelahan, 2007).

With regards to learning transfer, this concept is central to the debate about the utility of structuring a curriculum around Powerful Knowledge. In contemporary educational discourse there is ongoing debate about whether to primarily focus curriculum development around the notions of skills and competences, or around knowledge content. Within this debate there are concerns that skills and knowledge are being increasingly divorced from each other (e.g., see Didau (2013) as well as recent discussions around the Global Competency Framework from the Organisation for Economic Co-operation and Development (OECD) (2017)). In our earlier thinking on curriculum principles (Oates et al., 2019), we have argued that 'knowledge and skills' should not be considered to be dichotomous. We argue, with others, that knowledge underpins skills (Rotherham & Willingham, 2010), and that it is the abstraction of knowledge across contexts that provides the basis for highly competent behaviours (Salomon & Perkins, 1989).

2.1.2 Stage 2: Generating the subject framework descriptors

The integration of both inductive and deductive reasoning is an established approach for developing an understanding of a phenomenon (in this case, learning concept structures in different subject areas). Inductive reasoning involves using specific observations to build broader-level generalisations and theories, whilst deductive reasoning engages with established theories and generalised cases and relates these to specific cases. This integrated approach fits with a tradition in curriculum framework design, "[where] those responsible for setting educational goals may turn to tradition or evidence when seeking to revise curriculum and practice" (Jameson, 2016, p. 4).

In this project we wanted to draw upon and integrate information that was gathered from both inductive and deductive perspectives. For us, information gathered from an inductive perspective draws on information from across educational systems, and from which the analysis of patterns of behaviours and outcomes could allow us insight into how a subject has been structured in various systems. Information gathered from a deductive perspective engages with research outcomes and/or with experts who can use their experience and understanding of theory to make sense of the subject area. In a very general way, this process relies on the expert's careful consideration of the logic of the subject area to elicit the key areas of the domain, including consideration of its organisational features and interlinking concepts.

As part of an inductive approach we could draw on information about the structures of learning content from across different educational systems. The use of comparative data as a research evidence base for developing curriculum policy and practice reform is considered to be a generally useful approach (Burns & Schuller, 2007) since it is argued that there are common characteristics of successful systems (Schmidt, 2004). This approach has been used to inform curriculum development in the case of England and beyond (Creese & Isaacs, 2016; Karseth & Sivesind, 2010; Oates, 2011; Ruddock et al., 2008).

Curriculum mapping is a well-established approach that has been used in a variety of contexts to represent the relationships within and between curricula (Elliott, 2014; Greatorex, Rushton, Coleman, Darlington, & Elliott, 2019; Komenda et al., 2015; Plaza, Draugalis, Slack, Skrepnek, & Sauer, 2007). This representation then allows the main patterns across different curricula to be systematically gathered and related to each other.

In terms of curriculum framework development, mapping has a number of potential advantages. It can help to identify the most efficient ways of sequencing content in a curriculum framework; it can help to identify the ways that knowledge is represented at a social level across systems; and it can also help to identify which types of content are highly valued in different systems.

Educational systems can be compared using various metrics. For example, learner attainment outcomes across systems may be compared according to standardised metrics such as TIMSS, PIRLS or PISA[5] data. Where learners attain at a relatively high level in a particular system this may provide some empirical evidence that suggests that the way that the curriculum is organised is supporting learner development. Building on from other research that has looked to the messages gleaned from comparative methods as part of curriculum design, it is claimed that High Performing Jurisdictions (HPJs) reflect "the best collective wisdom we have about how children learn and what they should know" (Department for Education, 2011, p. 6).

By looking at how different systems have organised their curricula it is possible to gain insight into how the key elements of a subject domain have been defined at a social level (e.g. how a subject area is categorically divided into specific domains). This categorisation of knowledge is important since one ambition of a curriculum framework is that it conveys the generic characteristics of knowledge that can form the basis of transfer between systems. If a generic framework includes universal features, it can facilitate the movement of learners across the boundaries between different jurisdictions.

Educational system comparison can also be structured around contextual criteria. For example, mapping the curricula from systems that have relatively high levels of learner

[5] *Trends in International Mathematics and Science Study* (TIMMS) is a large-scale assessment designed to inform educational policy and practice by providing an international perspective on teaching and learning in mathematics and science. *Progress in International Reading Literacy Study* (PIRLS) has monitored trends in reading achievement at the fourth grade since 2001. PIRLS is administered every five years https://timssandpirls.bc.edu/. *Programme for International Student Assessment* (PISA) is the OECD's Programme for International Student Assessment. Every three years it tests 15-year-old students from all over the world in reading, mathematics and science http://www.oecd.org/pisa/.

inward migration can tell us something about learning content that might be considered important in such conditions. In addition, the parsimonious nature of a curriculum framework allows realistic goals for learners in disrupted settings where focussing on learning is hard; and ready mapping onto a wide range of national domestic curricula.

In contrast to the inductive approach to information gathering for framework development, it is also beneficial to consider the information that can be gleaned from a deductive perspective. This perspective highlights the importance of rational, *a priori* connections between ideas as a structuring device for curriculum design. A deductive approach to information gathering may use information from research evidence about how learning concepts in a subject area should be organised, or it can draw on the evidence of experts who use their experience and understanding of theory to help to sequence the arrangement of learning concepts. This process relies on a careful consideration of the logic of each subject area as a basis for eliciting the key areas of each subject domain, including consideration of organisational features and interlinking concepts.

Given the uncertainties around EiE contexts (outlined earlier), we recognised the importance of integrating both inductive and deductive approaches for our curriculum framework development. This dual approach had similarities to established approaches that interlink empirical observation and research as a way of optimising curriculum design (e.g. Smith, Wiser, Anderson, & Krajcik, 2006). By structuring curriculum design as an iterative process involving a dual approach, it would also be possible to mitigate some of the problems that could occur if designers' assumptions were based on the empirical route alone[6]. An iterative design process involving a dual approach sets out to establish, through both empirical evidence *and* theoretical reasoning, a hierarchy of conceptual understandings that proceed over the course of learning a subject (Lobato & Walters, 2017). It has been noted that high performing educational jurisdictions incorporate such a dual process (Valverde & Schmidt, 1998).

2.1.2.1 Stage 2.1 Defining content sequences that structure the framework

Another key element of the subject output work was to consider a methodology for sequencing the curriculum framework content. This sequencing leads into discussion around the potentially contentious notion of content *progression*. This concept is potentially problematic as it can be conceptualised in at least two ways, as a progressive and unfolding theoretical concept, or as a retrospective and empirically evidenced concept.

In the case of the first of these conceptions, there has been a significant amount of research devoted to identifying the key theoretical *Learning Progressions* across a variety of domains (e.g. Alonzo & Steedle, 2009; Catley, Lehrer, & Reiser, 2005; Fife, James, & Bauer, 2019; Jin, Shin, Hokayem, Qureshi, & Jenkins, 2017). Key characteristics of Learning Progressions are that they refine a theoretical, *a priori* optimal route to progression; they reinforce the idea that knowledge is domain-content specific; that knowledge has successive and progressive qualities; and that learning moves through stages (Gallacher & Johnson, 2019).

It is perhaps noteworthy that many of the proposed Learning Progressions are based around Science and Maths concepts, suggesting that the approach may be in some way

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[6] For example, see Gallacher & Johnson (2019) for a discussion of how high-level system analysis may overlook contextual details that could influence performance outcomes.

problematic for some other learning areas (e.g. Spiro, Coulson, Feltovich, & Anderson, 1988). There are also some concerns that there could be limitations around the extent to which theory can reflect the inconsistencies and complexities of the actual process of change that learners go through (e.g. Hammer & Sikorski, 2015). This sentiment is reflected in debates around complexity theory, which recognise that the outcomes of complex interactions can be difficult to predict because of the unpredictable cumulative impact of interacting factors. In this way it is possible to observe "how coherent and purposeful wholes emerge from the interactions of simple and sometimes non-purposive components" (Lissack, 1999, p. 112).

On the other hand, it is possible to conceptualise progression in learning empirically, through considering the actual pathways that learners have passed through on their way towards a specific learning outcome. This approach prioritises a reverse rationalisation process, whereby sense is imposed *a posteriori* on the progression through taking the learning outcome as the start of the enquiry and reconstructing the learner's route towards competence.

Taken together, these points suggested that it could be important to employ an approach where framework structuring was informed by both theoretical and empirical perspectives on learning sequences.

2.1.3 Stage 3: Establishing intra-subject coherence

The final stage of development represents the shift from a focus on the individual subject components of the curriculum framework to a focus on the complete framework itself. This shift from a focus on the individual subject components of the curriculum framework to the framework as a whole involves two related elements: establishing coherence across the content within each subject (intra-subject); and establishing coherence across the content of the different subjects within the framework (inter-subject). *Coherence* is a concept that is used to describe the contingent relations across the contents of the framework. Coherence is important as it is considered to be a key element that links to the impact of curriculum frameworks (Schmidt & Prawat, 2006).

We theorised coherence around the notion of *establishing common ground*, since the process of building coherence involves consensus-based activity across experts (both within a subject and across different subjects). The common ground notion holds that all collective actions are made possible where participants share a common underpinning understanding on which they can build a joint vision (Clark & Brennan, 1991; Littleton & Mercer, 2013). During this process, people need to assign sense to text (Culpeper & Haugh, 2014), and ensuring that this sense becomes a focus for shared action involves communication (Edwards & Mercer, 1987).

In the case of the development of coherence in a framework, the establishment of common ground would be the foundation for experts to identify the links between related concepts where they exist at different places across the framework. The background work for establishing common ground between subject experts could be supported through helping them to establish a common view of the intended goals at the project outset. This project-level common ground could be supported through discussion around the key principles that underpinned the framework as a precursor for experts establishing intra- and inter-subject level common ground (Johnson, Coleman, & Fitzsimons, 2019).

The establishment of intra- and inter-subject level common ground also required a discursive methodology that allowed the experts to identify the location of concepts across the framework. At the intra-subject level, the establishment of common ground could be supported through discussion around the linkages of concepts that have arisen through the inductive (mapping) and deductive (literature and expert review) phases of the development. At the inter-subject level, this discursive process would require subject experts to articulate the key concepts that structure their framework in ways that experts from other disciplines could relate to (so that these experts could identify points of commonality with their own subject sequences).

In this report we describe how intra-subject coherence was established for each subject in each subject section. We then describe how we dealt with inter-subject coherence in a separate section at the end of the report.

3 Maths framework development

We chose Maths as the first area for our framework development. Maths is an area where progressions in learning have previously been explored (e.g. Kim, Haberstroh, Peters, Howell, & Nabors Oláh, 2017), and our institutional partnership with Cambridge Mathematics allowed us insight into the latest thinking around curriculum development pathways. It was also possible that the types of knowledge that we were likely to encounter in Maths would be less problematic than the other subject areas in terms of the context-agnostic principle that pertained to the overall project.

3.1 Stage M1: Process of defining the subject framework principles and parameters

Throughout the Maths framework development process, the researchers in ARD worked closely with researchers and developers from a variety of organisations. We worked very closely with Rachael Horsman, Darren Macey, Ellen Jameson, Lynn McClure, and Tabitha Gould from Cambridge Mathematics. The Cambridge Mathematics organisation is a collaborative enterprise involving University of Cambridge partners that is committed to championing and securing a world-class Maths education for all learners based on evidence from research and practice[7]. ARD also worked with a variety of other consultants from within and from outside Cambridge Assessment, including Melise Camargo and Paula Beverley from Cambridge Assessment International Education, and Geoff Wake from the Centre for Research in Mathematics Education at the University of Nottingham.

As the development of the curriculum framework relies on the engagement of specialist subject and curriculum development experts, a crucial part of this process was to ensure that these experts were aware of the aims and scope of the project. At the first meetings with each external consultant we presented an outline of the *Education in Emergencies* context, including some contextualisation around major organisations and networks who work in this area, as well as their standards for ethical consideration when working in such contexts.

Beyond this broad context we oriented the experts to the theoretical underpinnings of the development project. We theorised this process around the notion of *boundary work* (Gasson, 2005; Wenger-Trayner, Wenger-Trayner, Cameron, Eryigit-Madzwamuse, & Hart, 2019). This idea explores how joint action involving multiple perspectives can be structured around the development of a shared focus on a specific object; in this case the curriculum framework document, and more specifically the concepts that underpinned this framework. It has been observed that an emphasis on communication, coordination and collaboration around a shared object (Star & Griesemer, 1989) helps to overcome the observed problems that often pertain to multi-agency working which can be undermined by the existence of diverse and competing challenges (Devitt & Borodzicz, 2008).

A final challenge related to contextualisation, which we felt could be a challenge to subject specialists (who may be more used to thinking about how learners *engage with* concepts as much as thinking about the concepts alone). We outlined at this stage how

[7] For more on the Cambridge Mathematics mission see: https://www.cambridgemaths.org/about-us/

the sequences that we were constructing would need to be adapted for use in a variety of contexts, but that this adaptation would take place at a local level (i.e. within an education sector where learners were located). We also reinforced, using photographs from a field visit to refugee learning centres in Bangladesh, how minimal the resource base for learning might be. We felt that this would help to guard against developers building assumptions around resource rich learning environments into the construction of the framework.

Once we had considered the issues of contextualisation, we took time at the expert consultant meetings to articulate the key principles that would underpin the framework development, and were based on Cambridge Assessment's earlier thinking on curriculum development (Oates, Johnson, & Coleman, 2019). These principles reinforced the importance of including content that conveyed something of the *foundational elements* of a subject area and which included core concepts (including threshold concepts[8]), key principles, fundamental operations, and core knowledge. Table 3 below describes these foundational elements, each of which are important for ensuring that the content of the framework had universal characteristics.

Table 3: Curriculum Framework Content Types

CONTENT TYPE		EXAMPLE
Concepts	Core	Fractions
	Threshold	The world as a sphere
Principles		Symmetry (rotating a cube doesn't change the cube)
Fundamental operations		Counting
Core knowledge		Know number bonds to 10

During these initial meetings we also discussed the notion of Powerful Knowledge. Young (2013, 2014); Young, Lambert, Roberts, & Roberts (2014); Young & Muller (2013) consider Powerful Knowledge to be predictive, explanatory and enabling the visualising of alternatives. Moreover, Young et al. (2014) identify three criteria for identifying Powerful Knowledge: (1) it is distinct from the common sense knowledge acquired through everyday life (so has abstract and general qualities); (2) its concepts are systematically related to each other (e.g. within a subject area); (3) it is specialised and developed by clearly distinguishable groups with a well-defined focus and relatively fixed boundaries, therefore separating out different forms of expertise. This notion has been used in educational discourse to explain why Maths is considered to have a particularly high status across different educational systems, with it also having a particularly high efficacy potential in terms of the benefits afforded to learners and society. This knowledge base also helps to explain why Maths is considered to be an important area of learning that encourages national development and equity enhancement (e.g., see United Nations Educational, Scientific and Cultural Organization, 2017).

Maton (2014) offers a technical explanation of why Maths is of central importance when developing a curriculum framework. Maths concepts can be said to have a high *semantic gravity*, because they have a high explanatory potential across an array of phenomena (e.g. an understanding of 1:1 correspondence can underpin counting, grouping, sharing,

[8] See Meyer & Land (2003) for more on this idea.

etc.). This *gravity* accords Maths an authority due to the generalising properties of its knowledge, meaning that it is useful for helping learners to access, make sense of, and ultimately, transform the world around them through being able to predict and control aspects of the material world.

The focus on Powerful Knowledge was reinforced in our contextualisation work by an outline of the notion of *threshold concepts*, and how these may help to inform the design of the framework structure in supporting the optimal routes for sequencing. The integration of threshold concepts, made popular by Meyer (2016) and Meyer & Land (2003), could add power to the framework through helping the designers to include concepts that are transformative, troublesome, irreversible, integrative, and often counter-intuitive (Perkins, 1999). In addition, these concepts are not sociocultural in character (Rata, 2012, 2019) as they have the ability to illuminate understanding beyond the immediate culture of locally reproduced learner knowledge (i.e. so that learners can think about concepts that they do not encounter in their everyday experience).

To start to get a sense of the ways that Maths is conceptualised and organised across different systems we carried out a mapping exercise. This approach allowed our development to incorporate an inductive perspective whereby we could explore the commonalities of the ways that Maths was structured across different educational systems. For example, the consideration of data from across educational systems would allow our development process to be informed by evidence from systems where learners were generally attaining at good levels of mathematical performance. The value of this sort of analysis rests on a logic that suggests that these data provide some empirical evidence that the sequences that structure these systems support learner development. The use of comparative data as a research evidence base for curriculum policy and practice reform is considered to be a generally useful approach (Burns & Schuller, 2007) since it is argued by some that there are common characteristics of successful systems (Schmidt, 2004). As a result, this approach has been used to inform curriculum development across a variety of contexts (Creese & Isaacs, 2016; Karseth & Sivesind, 2010; Oates, 2011; Ruddock et al., 2008).

To begin this process, we wanted to consider performance outcomes data from some common learning metrics, such as TIMSS, PIRLS and PISA assessments. We identified High Performing Jurisdictions (HPJs) using a method suggested by Elliott (2016). This approach identifies HPJs as those that are in the top 20 positions of at least six out of seven large scale education comparisons[9].

The use of this criteria led to the identification of seven HPJs: Australia, China (Taipei), Finland, Hong Kong, Japan, Singapore, and South Korea. In the case of Australia, education is devolved to states with each having its own curricula. Consequently, Victoria, a high performing state, was selected to represent Australia in the curriculum comparison exercise. We could not locate English language versions of the South Korean or the Chinese Taipei curricula. This meant we discounted South Korea from our analysis. We managed to secure access to translations of the Chinese Shanghai curriculum. Although China did not meet the HPJ definition (since it was not entered into the TIMMSS and PIRLS datasets), China-Shanghai had the highest ranking in each

[9] TIMSS 2011 (8th Grade Science); TIMSS 2011 (8th Grade Maths); PIRLS 2011 (Reading); PISA 2012 (Reading); PISA 2012 (Maths); PISA 2012 (Science); The Global Index of Cognitive Skills and Educational Attainment 2014.

of the 2012 PISA comparisons (Elliott, 2016). Therefore, we decided to include it in our curriculum comparison.

In addition to the highest performing jurisdictions, we also decided to include a number of additional curricula from jurisdictions that had been highlighted as fast improving according to the UK National Curriculum review (Department for Education, 2011). This added Unites States (Massachusetts), New Zealand, and Canada (Alberta) to our analysis. Table 4 lists the curriculum documents that were consulted in the review process.

Table 4: Maths Curriculum Mapping Sources

Curriculum		*Year*	*Level/Stage*
Australia	Victoria	2016	F - 10A
Canada	Alberta	2016	K - 9
China	Shanghai	2011	1 - 9
Finland		2016	1 - 9
Hong Kong		2017	K - S6
Japan		2008	1 - 9
United States	Massachusetts	2017	Pre-K – 12
New Zealand		2007	1 - 13
Singapore		2013	P1 – S4

Once the HPJs were defined, a researcher analysed all the curriculum documents to identify the high-level organising categories for the mathematical knowledge that was included in each of the curricula of these HPJs (e.g. for these domains included ‘Number, ‘Algebra’ etc.). This allowed the documents to be related to each other for comparison purposes (Table 5).

Table 5: Extract from the High-Level Curriculum Comparison Exercise

	AUSTRALIA (VICTORIA)	**CANADA (ALBERTA)**	**FINLAND**	**HONG KONG**	**…**
PRIMARY	Measurement and Geometry Number and Algebra Statistics and Probability	Strands Number Patterns & Relations Shape and Space Statistics and Probability Also have ‘Mathematical processes’ which are indicated next to content	Thinking skills (and methods, if grade 7 onwards) Numbers and Operations Algebra (from grade 3) Functions (from grade 7)	Number Algebra (from P4) Measures Shape & Space Data Handling	
…	…	…	…	…	

The next stage of the framework development process involved the development of a generic matrix that contained all the elements of the different curriculum documents being compared. In general, there was a broad consensus around the domains represented across the different curricula (Table 6). A closer review of the curriculum documents revealed that the main domains were commonly broken down into several subdomains (e.g. Number included subdomains of 'System', 'Counting', 'Naming' etc.).

Table 6: Common Domains of Mathematical Curricula

COMMON DOMAINS		
NUMBER (4 OPERATIONS, FRACTIONS AND DECIMALS)	Measurement	Geometry
STATISTICS	Algebra	

The identification of these domains (and subdomains) allowed us to develop a large matrix to collect and compare the sequences, with each of these domains forming the vertical column of the initial matrix (Table 7). This was the initial work that enabled us to work on the next development stage (defining the content sequences).

Table 7: Initial Maths Matrix (Extract)

	A	B	C	D	E	F	G
1	Domains	Sub Domains	*Main concept*	1	2	3	4
2	Number (whole number and 4 operations)		*Number system*				
3		Addition (NA)	*Counting*				
4			*Naming / Conserving*				
5			*Subitising / Estimating*				
6			*Comparing*				
7			*Ordering / Sequencing*				
8			*Adding*				
9			*Place value*				
10		Subtraction (NS)	*Subtracting*				
11		Multiplication (NM)					
12		Division (ND)					
13	Fractions & Decimals (and 4 operations)	Decimals (FDD)					
14			*4 operations*				
15		Fractions (FDF)	*Fractions as parts*				
16			*Comparing*				
17			*Addition*				
18			*Subtraction*				
19			*Mutliplication*				
20			*Division*				
21		Percentages (FDP)					
22			*4 operations*				
23	Measurement	Length (ML)					
24		Time (MT)					
25		Volume (MV)					
26		Money (MM)					
27		Angle (MAn)					

3.2 Stage M2: Generating the subject framework descriptors

We were aware of some the limitations of curriculum document review as a source of evidence for framework development, and so we felt it was important to engage with experts and with research literature to augment the documentary data sources. This dual approach (employing both empirical evidence *and* theoretical reasoning) would allow us to establish a consensus around the content sequences in our framework.

The use of mapped curriculum data in conjunction with expert consultation to inform curriculum development has similarities to established approaches that interlink empirical observation and research to optimise curriculum design (e.g. Smith, Wiser, Anderson, & Krajcik, 2006). Such approaches set out to establish, through empirical evidence and theoretical reasoning, a hierarchy of conceptual understandings that proceed over the course of learning a subject. It has been noted that high performing educational jurisdictions incorporate such a process (Valverde & Schmidt, 1998), which might support a conclusion that such a process is useful for organising a programme of learning. According to Lobato & Walters (2017), this approach to progression synthesises experts' knowledge of the domain with evidence from studies of student knowledge and learning. This process then leads to the unpacking of a hierarchy of target learning constructs.

The first stage of content sequencing involved three researchers from ARD organising the curriculum statements for each of the domains and subdomains of each HPJ curriculum document (Table 8).

Table 8: HPJ Curriculum Statement Sequences (Extract)

1		Jurisdiction	L2	L3	L4	L5	L6
2	Number	*Australia*	Number sequence 2, 3, 5, 10 Order numbers >1000 Partition 100s/10s/1s Multiplication as repeated addition/ groups/ arrays Division as equal groups Division as repeated subtraction Half, quarter, eighths of shapes and groups	Odd and even numbers Order numbers >10 000 Recall addition/ subtraction facts (single digits) Recall multiplication/ division facts: 2, 3, 5, 10 Unit fractions and multiples to a whole Inverse operations (number machine)	Number sequences 3, 4, 6, 7, 8, 9 Recall multiplication/ division facts to 10x10 Multiply/ divide without remainder Equivalent fractions Thirds Link fraction/ decimal notation	Order numbers>100 000 Factors/ multiples of whole numbers Estimate/ round to check reasonableness Multiply 2-digit numbers Divide by 1-digit number with remainder Compare/ order unit fractions Add/ subtract fractions with same denominator Place value beyond 100ths Compare/ order decimals	Pri tri 10 Ad re Si qu Ad Mu by po Lin pe
3		*Finland*	Naming numbers/ quantities (number and sign) Order numbers Decomposition of numbers (1-10) Addition/ subtraction>100 Addition: commutative/ associative properties	Multiply/ divide (2s) Multiplication facts: 1s-5s, 10s Link multiplication facts to division Multiplication: commutative/ associative properties Decimal system (concrete models) Fractions: link to division/ equal parts	Basic mental operations Addition/ subtraction algorithms Multiplication: 6s-9s Multiplication algorithm Division as quotition and partition Number sequences (rules)	Rounding Approximation Negative numbers/ negative integers Fractions Basic operations with decimal numbers Foundations of percentages Link fractions, percentage, decimal numbers	
		USA	Word problems: add/	Multiplication/ division	Multi-step problems with	Decimals: thousandths/	Ra

Once this was done across all of the domains for all of the HPJs, the researchers were able to elicit the patterns of sequences from each of the domains and subdomains to create a draft *master sequence* (Table 9). This process required the use of mathematical judgement, and so it was carried out by two researchers with a background in Maths teaching and learning. To do this, the principal patterns of conceptual sequence were plotted for each domain/subdomain. This involved analysis of the sequencing patterns that were noticeable across a number of the reviewed curricula (e.g. *basic addition, subtraction, multiplication, and division with decimal numbers* → *multiplication and division of decimals by whole numbers and powers of 10* → *addition, subtraction, multiplication, and division* *of decimals to 100th* was a common pattern across Finland, Australia (Victoria) New Zealand, Japan, China (Shanghai), and United States (Massachusetts) curricula).

Table 9: Draft 'Master Sequence' (Extract)

	A	B	C	D	E	F	G	H	
1	**Domains**	Sub Domains	*Main concept*	1	2	3	4	5	6
2	**Number (whole number and 4 operations)**		*Number system*	Odd / even numbers [U2 / C2 / A3 / Ch4.6]	Negative numbers [F5 / U6 / HKS1 / J7 / Ch4.6]	Prime numbers [A6 / HKP4 / NZ5 / Ch4.6]	Square, composite, triangular numbers [A6 / HKP4 / Ch4.6]	Square roots [A7 / U8 / F9 / NZ5 / Ch6.7]; Cube roots [U8 / Ch6.7]	Ratio numb Ch6. Nega ratio numb [HKS
3		Addition (NA)	*Counting*	Count objects < 20 [UK / C1 / NZ1 / J1]	Count < 100 [U1 / UK]; Count forward and backward [NZ1]	Count < 1000 [U2]	Skip count: 2, 5, 10 [A1 / C1]	Skip count: 3, 4, 100, 25 [C3]	
4			*Naming / Conserving*	1:1 correspondance [UK]; recognise concept of whole numbers [HKP1]	Name numbers < 20 (last number is the name) [UK / C1 / F2 / NZ1]				
5			*Subitising / Estimating*	Subitise objects [AK]	Subitise < 5 [CK]	Subitise < 10 [C1]	Estimate greater / less than [UK]	Estimate < 1000 [C3 / Ch4.6]	Estim chec reas s; Appr [A5 /
6			*Comparing*	Compare quantities < 10 [CK / J1]	Compare numbers as a sum or difference < 20 [C1 / J1]	Compare numbers as a sum or difference < 100 [C2 / J1]			
			Ordering / Sequencing	Order numbers [F2 / NZ1];	Number sequences	Number sequence 2, 3,	Order numbers < 1000 [C3];	Order numbers < 10 000 [A5];	Orde < 100

Again, recognising the limitations of using document mapping as a sole method for framework development, we needed to integrate the perspectives of experts and of research (theory) into the development process. In this way, the master sequences were a tool for critique and reflection as part of this development process, which involved a series of meetings with experts from Cambridge Mathematics, Cambridge Assessment International Education, and the University of Nottingham. Below we outline how we developed our framework in the different mathematical domains.

3.2.1 Stage M2.1 Number, Measurement, Geometry, Algebra

Initial review work with Cambridge Mathematics experts showed that most of the mapped domains overlapped with content that was covered in the emerging framework that Cambridge Mathematics were developing as part of a 5-year initiative (Cambridge Mathematics, 2019b). This framework is a multi-dimensional, connected structure of Maths that is influenced by theoretical perspectives, international evidence, and empirical research. It aims to support curriculum design as it contains multiple paths through Maths, and so designers, aided by information from the research base, can make informed choices about which learning pathways to construct.

The review work with Cambridge Mathematics experts was carried out over a series of 14 meetings and workshops. These meetings explored the domains identified through the curriculum mapping exercise to determine the extent of coverage overlap with the emerging Cambridge Mathematics Framework. The outcome of this exploration was that there was overlap between the content identified in the curriculum mapping exercise and in the Cambridge Mathematics Framework. These overlaps were in the domains of Number, Measurement, Geometry (and Shape), and Algebra, and suggested that the data from the Cambridge Mathematics Framework would be able to support the development of learning sequences for our curriculum framework. This left only the Data Handling and Statistics domains as an area where a different approach to development would be needed (see section below).

The development meetings for each domain refined the mapped curricula into a series of sequences using pre-defined, research-based principles to steer the process. Following an initial meeting to choose the order of domains to structure the framework development[10], subsequent meetings were structured around a common organisational pattern of expert curriculum mapping review and revision work:

1 Expert curriculum map review: This was structured around a series of questions where recommendations were sought on:

- Which subdomains to use
- The relationship between subdomains
- Which concepts overlap (leading to decisions to merge)
- Which concepts are not necessary (leading to decisions to remove)
- Which concepts are central (leading to decisions to retain)
- Whether the order of sequence is advisable

2 Revisions to the emerging curriculum framework: At this stage the meetings focused on:

- Whether the framework still included the key/salient concepts (following the removal of concepts during the previous expert meetings)
- Which key/salient concepts linked to other domains (e.g. comparing number and measurement), and where these should reside
- Aligning the key/salient concept sequences for subdomains where there were overlaps
- Checking the sequences inherent to each key/salient concept (removing superfluous detail so as to focus on which concept comes first)

Reviewing key/salient concepts and imposing order on their inter-relationship (to show the progression of conceptual understanding)

Although adhering to the same design principles, this review and refinement process differed across domains, reflecting some of the differing characteristics of each domain. For example, the discussions at each meeting were always informed by additional literature that was identified as being important by the experts. For example, discussions about number sequences were informed by personal communications with international

[10] Number was chosen as the first domain for development as it included underpinning concepts that aid progression in other mathematical areas. Measures was considered suitable for the second phase of development as this also included bridging concepts that link with other areas.

researchers around the draft OECD Mathematics 2030 Learning Framework, with this building on the work of Schmidt (2004), whilst the statistics strand brought in work from Ben-Zvi (2004), Langrall, Makar, Nilsson, & Shaughnessy (2017), Noll & Shaughnessy (2012), Reading & Reid (2006), and Watson, Callingham, & Kelly (2007). This refinement process also meant that the character of representation of concepts differed across domains. Discussions around the content of sequences in Statistics were more oriented to considerations about process than those in the Number domain which focused more heavily on concept and content (this is discussed more in the next section).

The next part of the framework refinement process involved seven phases across each of the *Number, Measurement, Geometry*, and *Algebra* domains. These phases were: (1) Exploring the curriculum mapping sequences; (2) Relating the mapped sequences to waypoints in the Cambridge Mathematics Framework; (3) Analysis of the emerging picture of the concept sequence; (4) Restructuring the concept sequence; (5) Refining the concept sequence statements; and, (6) Drafting the final linear concept sequence. To exemplify this refinement process, we use the development of the *Shape* subdomain of *Geometry* as a case study.

(1) Exploring the curriculum mapping sequences. At this phase Cambridge Mathematics experts extracted a particular subdomain learning sequence that was previously produced through the mapping exercise (Table 10). They started to explore the sequence to identify any discrete elements (e.g. shape sorting concepts; characteristics of particular shape types; dimensionality concepts).

Table 10: Shape Subdomain from the Geometry Curriculum Mapping Exercise

Shape 1	Shape 2	Shape 3	Shape 4	Shape 5	Shape 6	Shape 7	Shape 8
Describe objects *[UK / NZ1 / J1]*; Sort objects (1 & 2 attributes) *[C1 / C2]*	Sort / describe 2D / 3D objects *[AK / CK / A2 / F2 / HKP1 / NZ4 / Ch1.3]*; Composite shapes *[C1 / J2]*	Defining features of shape; Compare / describe 2D shapes: triangle, square, rectangle, circle, rhombus, trapezoid, pentagon, hexagon *[U1 / C2 / U2 / F5 / C3 / J5 / HKP1 / J2 / Ch1.3]*	Triangles (scalene, isosceles, equilateral, right) *[C6 / HKP1 / J3 / Ch4.6 / A7 / Ch6.7]*	Lines: Perpendicular, Parallel, Intersecting *[HKP1 / U4 / J4 / C5 / J7 / Ch6.7]*	Compare 3D objects: cube, sphere, cone, cylinder, pyramid *[C2 / U2 / F4 / HKP4 / J3 / Ch1.3]*; Prisms *[C4 / NZ3]*	3D nets / models [A5 / HKP4 / NZ4 / NZ5 / U6 / C8]; Vertices and edges [HKP4 / C3 / Ch6.7]; Faces [U2 / HKP1]	Circles: relations between radius, diameter, circumference *[C7 / U7 / J5 / Ch6.7]*; Pythagoras *[A8 / F8 / U8 / C8]*

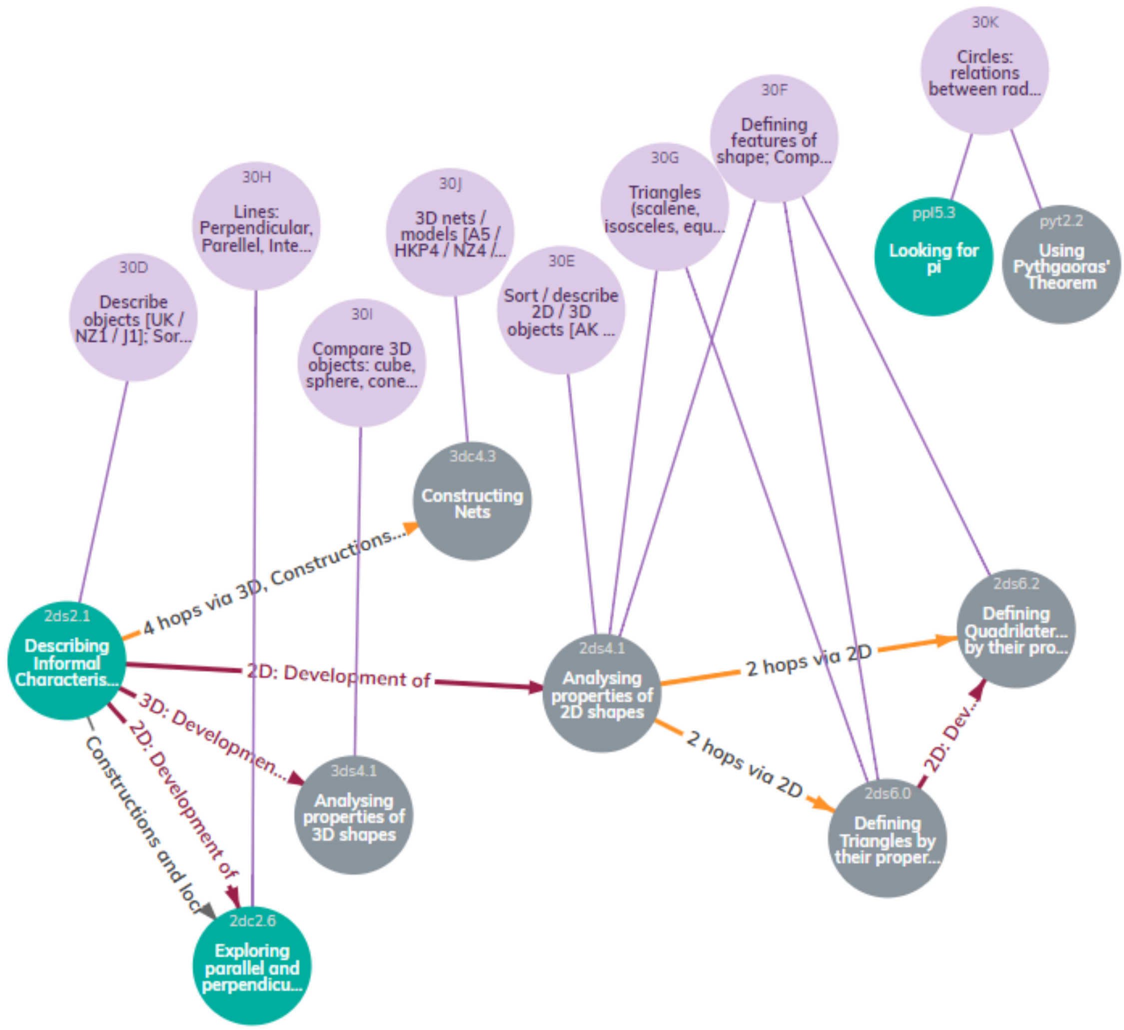
(2) Relating the mapped sequences to waypoints in the Cambridge Mathematics Framework. The Cambridge Mathematics Framework includes a series of waypoints that can be used as a tool to model a learning pathway from less to more advanced mathematical understanding.

These waypoints, derived from extensive research literature, indicate the key underpinning concepts that contribute to understanding of larger, more expansive concepts. Furthermore, the convergence of waypoints, around specific concepts on the pathway, help to signal those concepts that may be particularly important as they represent points of cumulative understanding that learners need to attain if they are to continue to grow as mathematical thinkers.

These points of convergence are also important as they help analysts to plot the most efficient pathway through the concept framework. The points of convergence help to identify the shortest route between concepts by indicating the number of concept *steps* that separate one concept from another.

At this phase of our development process the experts from Cambridge Mathematics applied the content from our curriculum mapping exercise to the waypoints within their own framework. Figure 1 shows the initial linkage of the concepts outlined in our curriculum mapping exercise with the waypoints from the Cambridge Mathematics Framework. At this initial stage, the linkage shows that the sequence from the curriculum mapping exercise produces a progression that coheres with the research underpinning the Cambridge Mathematics Framework. This is shown by the way that the concept order from the curriculum mapping exercise mirrors that of the Cambridge Mathematics Framework. The figure also indicates the number of conceptual steps between the waypoints in the framework.

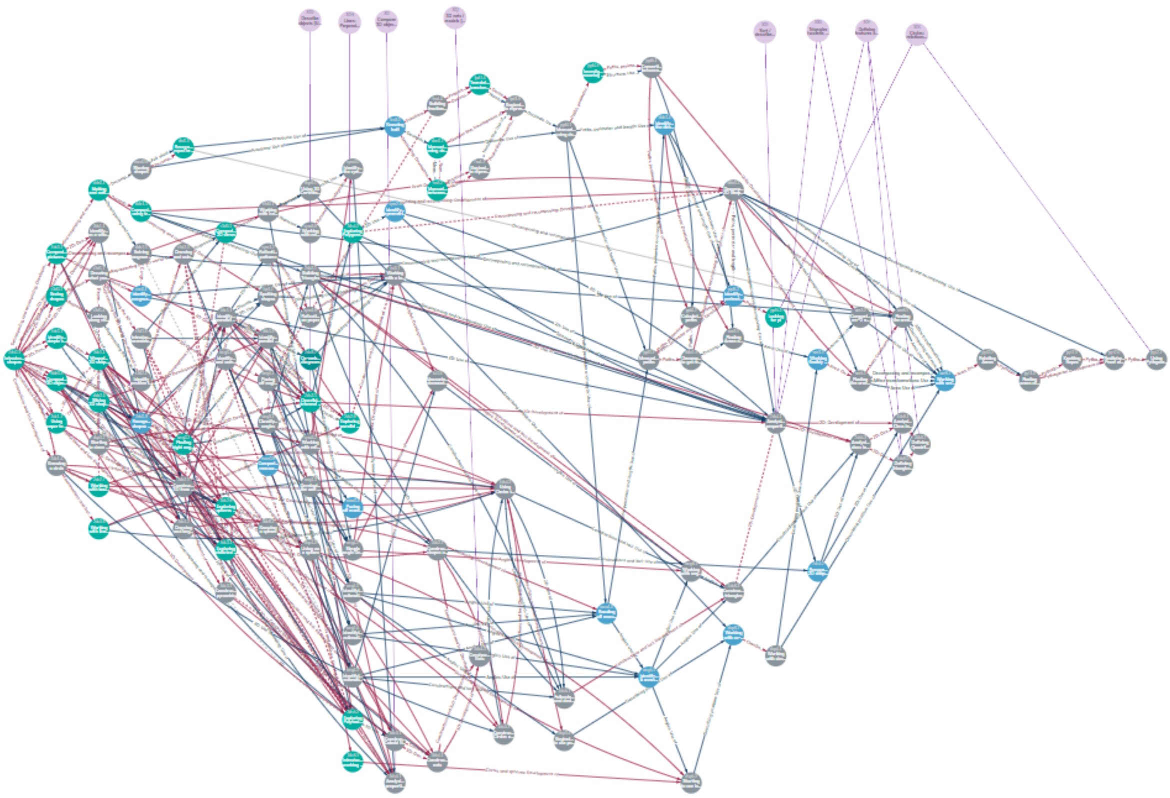
Figure 1: Shape Concepts from the Curriculum Mapping Exercise linked to the Cambridge Mathematics Framework



(3) **Analysis of the emerging picture of the concept sequence**: At this phase there was specialist analysis of the linkages that emerged from plotting the mapping exercise and the Cambridge Mathematics Framework (Figure 1). This close analysis indicated that there was a break in the sequence (with circles being isolated from the rest of the sequence), suggesting that there were two communities of waypoints for the Shape subdomain.

To explore this further, experts from Cambridge Mathematics analysed the sub-map that lay beneath these waypoints using an algorithm that looks for and prioritises connected pathways between the chosen set (Figure 2). The sub-map shows how the sequence from the mapping exercise relates to the multitude of concepts and waypoints contained within a section of the Cambridge Mathematics Framework.

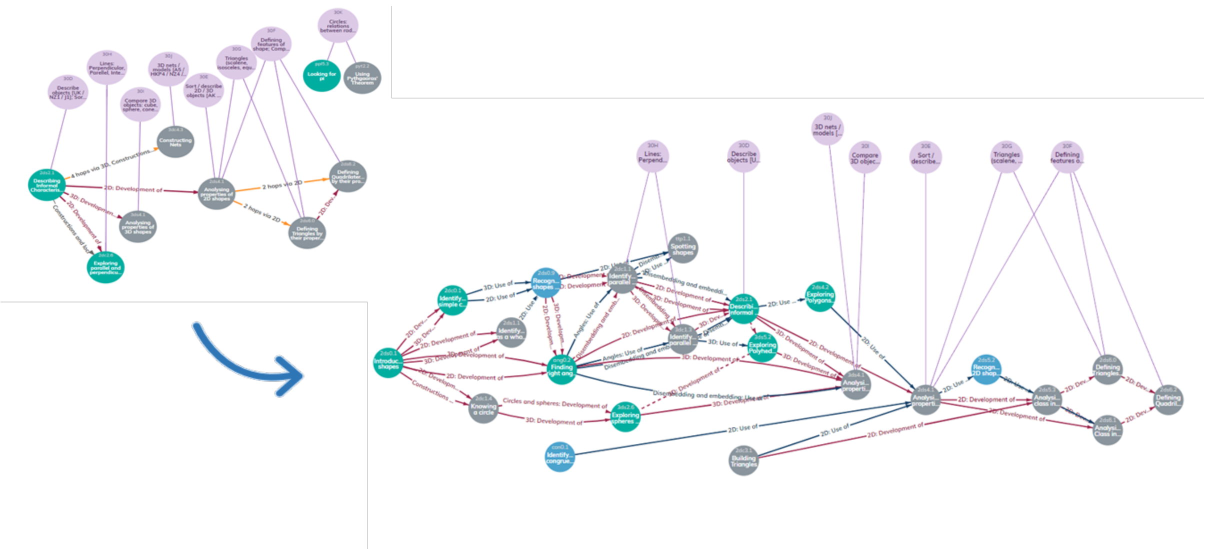
Figure 2: Submap for Specifically the Waypoints Preceding "Describing Informal Characteristics".



This sub-map analysis showed that the emerging framework based on the curriculum mapping exercise included detail for all but four components that were important for this Shape sequence: Decomposition; Constructions and Loci; Symmetry; and, Representing 3D Space. These components are considered to be important as they feed into understanding shape properties and the representation of shape.

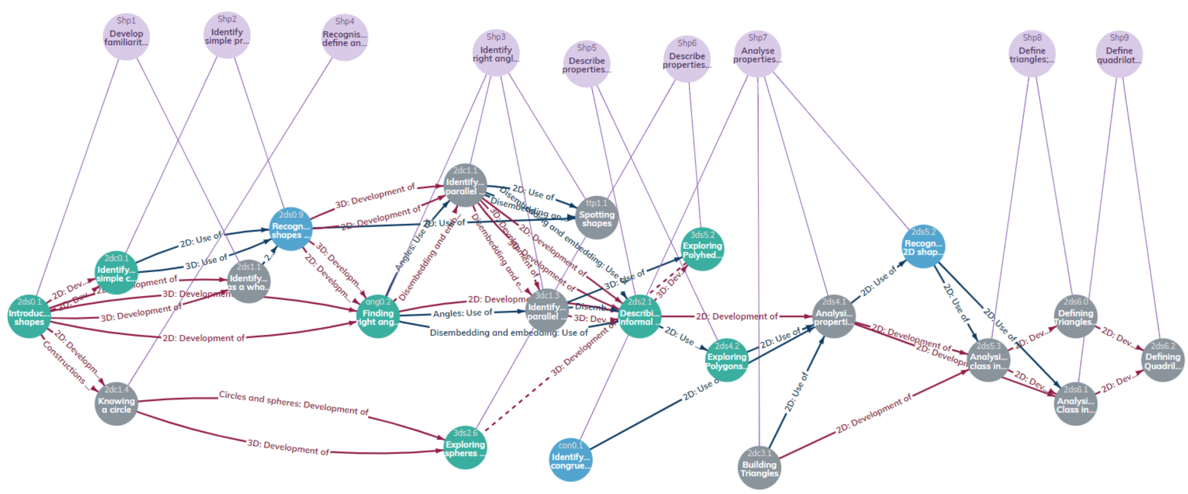
(4) **Restructuring the concept sequence:** The sub-map analysis led to several suggestions around component restructuring. These included: Removing Pythagoras from this sub-domain to place in its own sub-domain; Removing Area and Circumference of a Circle from this sub-domain and placing in Measurement; Removing Nets from this sub-domain and placing in a new sub-domain for Constructions; Adding new sub-domains for Symmetry and Representing 3D space; Using van Hiele theory to clarify the level at which shapes are being analysed. This led to a reconceptualization of the conceptual linkages that should underpin the curriculum framework sequence to include more elements, specifically at the earliest stages of the sequence. (Figure 3) shows the original model of the concept sequence (Figure 1) alongside the new sequence that emerged once sub-map analysis had taken place.

Figure 3: Reconceptualised Learning Sequence for Shape



(5) Refining the concept sequence statements: At this phase the Cambridge Mathematics experts were able to consider whether the high-level statements (that would form the curriculum sequence statements for our framework) adequately covered the components that emerged from the sub-map analysis. At this phase the experts added an additional two high-level statements to the framework (Figure 4).

Figure 4: Refined Curriculum Model



(6) Drafting the final linear concept sequence: The final development phase involved the experts re-writing the statements that comprised the sequence so that they clearly represented the concepts within them (Table 11).

Table 11: The Final Sequence for Shape

SHAPE 1	SHAPE 2	SHAPE 3	SHAPE 4	SHAPE 5	SHAPE 6	SHAPE 7	SHAPE 8	SHAPE 9
DEVELOP familiarity with and identify (as a whole) 2d and 3d shapes, without relying on properties.	Identify simple properties of 2D and 3D shapes such as number of edges, equality of edges.	Recognise, define and construct a circle.	Identify right angles, parallel and perpendicular lines and faces in 2D and 3D shapes.	Describe properties of 2D shapes in terms of symmetrical properties, equality of angles and side lengths. Recognise and identify 2D shapes using the above properties.	Describe properties of 3D shapes in terms of faces, equality of faces/edges, and cross-sections. Recognise and identify 3D shapes using the above properties.	Analyse properties of 2D shape, consider the hierarchy and family links between shapes.	Define triangles; recognise necessary and sufficient conditions. Identify with respect to definitions examples and non-examples.	Define quadrilaterals; recognise necessary and sufficient conditions. Identify with respect to definitions examples and non-examples.

Over a series of around 10 meetings and workshops we were able to adopt this methodology to refine the concept sequences for the rest of Geometry (beyond Shape), Number, Measurement, and Algebra.

3.2.2 Stage M2.2 Data Handling and Statistics

As already outlined, we were able to identify some areas of overlap between some of the mathematical content identified in the curriculum mapping exercise and content that was already covered in the Cambridge Mathematics Framework at that stage of its development. One area where there was no overlap was in the Data Handling and Statistics domains, which meant that we could not adopt the same approach to development as we had adopted for Number, Measurement, Geometry and Algebra.

In keeping with the development that we had carried out already, we wanted to maintain our connection with the Cambridge Mathematics Framework and the experts who were developing that framework. At the initial meetings we explored the curriculum mapping outcomes with an expert from Cambridge Mathematics. As a consequence of this reflection, a considered outcome was that there were some areas of Data Handling and Statistics coverage that were missing from the mapped framework, and that there were other areas included where the latest thinking would suggest these to be inappropriate. Initial reflections, based on the emerging work of the Cambridge Mathematics experts, were that there was a tendency to overpopulate Data Handling and Statistics curriculum frameworks with content and techniques.

Drawing on the work of Wild (2006), whose perspective is influential on the early development work in this area of the Cambridge Mathematics Framework, there should be a focus on collecting data to solve problems and to see connections and patterns in these data. Wild argues that "the key drivers for successful statistical practice, and thus the most critical elements to be instilled by statistics education are three propensities: the propensity to collect data that usefully addresses the question of interest, the propensity to question the applicability of data to the problem in hand, and the propensity to seek meaning in data. Everything else is about how to act on these propensities" (Wild, 2006, p. 23).

As a way forward for developing our framework we convened a workshop to start to structure this domain. This workshop involved an expert from Cambridge Mathematics along with an expert from the University of Nottingham and had four phases: establishing a shared vision of the domain; identifying the structure of the subject domain; identifying the subdomains; and defining the sequences of conceptual development within those subdomains.

As a precursor to determining the fundamental ideas/concepts of Data Handling and Statistics that learners should learn by the age of 14, the first phase of framework development involved the experts generating a statement that would guide their concept sequencing work (Figure 5). This joint statement highlighted that there were expert concerns in literature around the ways that Data Handing and Statistics is structured and represented in some different curriculum models. More specifically, the experts wanted to avoid instrumentalist and superficial approaches to the domain, and to encourage an approach that centred on engagement with data and statistics through the purposeful application of content to meaningful problems.

Figure 5: Joint statement to guide Data Handling and Statistics concept sequencing

"Fundamental to the approach taken from the outset should be that learners experience working with data and statistics as a response to a desire to interrogate and make sense of the world in which they live. This means that throughout their work learners should be mindful that the work they are doing is in response to a meaningful question. This may involve learners in working so as to be able to communicate what they find, or alternatively, to critically interrogate the work of others so as to understand its validity. This will involve learners in engaging with what is usually considered a statistical problem-solving cycle, either in its entirety, or in part. Such a cycle emphasises that a question is central and is the reason why we collect and organise the data. This question informs the measures we calculate and the diagrams/charts/graphs we use to provide us with meaningful insights. In addition to providing such insight into the situation we use these measures and representations to communicate our analysis to others, interpreting what we find in ways that seek to provide clear answers to the original question. Recognising that we live in a world where the outcomes of such work are presented to us in many different forms on a daily basis, learners should have experience of interrogating and making sense of such work in ways that are potentially critical of outcomes"

(Data Handling and Statistics workshop meta statement).

The next phase of the development was a discussion around how the fundamental ideas and concepts of Data Handing and Statistics should be structured. For this, drawing on the work of Steen (1990), the experts identified two major subdomains: Data Handling; and Risk. Within the Data Handling subdomain, the experts identified three main areas for conceptual sequencing: Understanding and working with data; Considering data distribution variability measure and representations; and, Working with time series and bivariate data. For the Risk subdomain, the main concept for sequencing was organised around Using probability to understand issues of risk.

Following the identification of the two major subdomains, the experts spent time generating the sequences of conceptual progression in each subdomain. To do this, the experts discussed and identified what the endpoints of the learning sequences for each of these subdomain strands would be. Once these were defined, through consensus, the experts were able to use the curriculum mapping framework as a resource for critical reflection during the process of sequencing the concepts across the subdomains.

The final development phase involved experts at Cambridge Mathematics mapping the concepts of the *Data Handling and Risk* sequences to those that have now emerged within their own framework. This mapping was a validation process like that carried out for the development of the other mathematical domains of our framework. It is of interest to note that the *Data Handling and Risk* concepts that form part of our framework have overlapping similarities with the concepts of *Uncertainty* that are informing the latest mathematics frameworks emerging from the Organisation for Economic Co-operation and Development (OECD, 2019).

3.3 Stage M3: Establishing intra-subject coherence

The establishment of coherence in Maths had two dimensions: establishing coherence of the domain sequences that were located within the Cambridge Mathematics framework; and establishing coherence between the Data Handling and Risk domain and the rest of the framework. The establishment of coherence for those descriptors found within the Cambridge Mathematics framework was supported by the underlying structure of the framework. In the Cambridge Mathematics framework content is organised around a series of interconnecting Waypoints (Cambridge Mathematics, 2019a). The connections between these Waypoints allow the experts to identify potential learning sequences based on the underlying empirical and theoretical data that underpin the framework. Moreover, the experts are able to look at the number of steps between interconnections to consider if some pathways are more efficient in terms of needing fewer connections along a learning sequence.

The Data Handling and Risk domain was jointly developed by experts from Cambridge Mathematics and the University of Nottingham. Establishing coherence between this domain and the rest of the Cambridge Mathematics framework involved reflective work by the Cambridge Mathematics experts. This involved referencing the descriptors of the Data Handling and Risk domain to those that were recently developed within the Cambridge Mathematics framework.

At the conclusion of this intra-subject coherence review phase, the development team began work to support inter-subject coherence across the different subject areas within the LP framework. This will be further discussed in section 7 of this report.

4 Maths framework

4.1 Maths framework overview

Domains	Main concept	Code
Number (whole number and 4 operations)	Understand Naming, Conserving, and Counting	C
	Understand the number system	N
	Understand Subitising / Estimating	SE
	Understanding Place Value	PV
	Understanding Adding and Subtracting	AS
	Understanding Multiplication and Division	MD
Fractions, Decimals & Percentages (and 4 operations)	Understanding Decimal System, Equivalences, and Place Value	DEP
	Understanding Adding and Subtracting (Decimal)	ASD
	Understanding Fractions as Parts and Equivalences	FPE
	Comparing Fractions	CoF
	Understanding Adding and Subtracting (fractions)	ASF
	Understanding Percentage and Equivalences	PE
	Understanding Multiplication and Division (Decimal)	MDD
	Understanding Multiplication and Division (fractions)	MDF
Geometry	Shape	Shp
	Position-Space	P-S
	Symmetry and Isometric transformations	SIT
	Constructions	Con
	Congruent and similar shapes	C&S
	Pythagoras	Pyt
Measure	Length	Len
	Area	Are
	Volume/Capacity	Vol
	Angle	Ang
	Weight	Wei
	Time	Tm
Algebra working and thinking	Equivalence	EQ
	Inequalities	INQ
	Relationships + Functions	RF
	Patterns + Functions	PF

	Change + Functions	CF
Data handling	Understanding and working with data.	UWD
	Considering data distribution variability measure and representations.	DVM
	Working with time series and bivariate data	TSB
Risk	Using probability to understand issues of risk.	P&R

4.2 Detailed Maths framework

DOMAIN	MAIN CONCEPT	CODE	FOUNDATION 1[11]	FOUNDATION 2	FOUNDATION 3
Number (whole number and 4 operations**)**	Understand Naming, Conserving, and Counting	C	Match elements of two collections of objects in one-to-one correspondence and use this to compare their numerosity. Partition and re-partition a collection of objects into those that have been counted and those that have not.	Use singular and plural words. Develop and awareness that numbers exist and notice them in the everyday environment. Begin to connect conventional number names and their corresponding symbols.	Learn, memorise and recite the conventional sequence of whole number names from zero to, at least, ten. Recognising that number names can be attached to objects as labels.
	Understand the number system	N			
	Understand Subitising / Estimating	SE	Relate number names to objects or groups of objects. Determine the number of items in a set without counting.	Compare two quantities based on numerosity (count) or magnitude (size). Place two or more objects (or symbols) in some order based on a given attribute	
	Understanding Place Value	PV			
	Understanding Adding and Subtracting	AS			Work flexibly with additive triads up to 20, using objects, images and, later, symbols.
	Understanding Multiplication and Division	MD			

[11] Foundation 1, 2, and 3 identify the *foundational ideas* that need to be encountered prior to engaging with the ideas located in Level 1 of the Science Framework. These Foundation levels are not tied to years, and we would anticipate that some form of diagnostic measure would be used at an initial stage to place a learner at an appropriate learning level in the framework.

DOMAIN	MAIN CONCEPT	CODE	1	2	3
Number (whole number and 4 operations)	Understand Naming, Conserving, and Counting	C	Count using conventional number words and connecting the successor principle, ordinality and cardinality. Begin to use the number line as model for the counting numbers. Recognise that every (whole) number has a succeeding number.	Recognise patterns in the structure of conventional number symbols and number names. Count on and count back.	Count on in ones, twos, threes, fours etc. as a more efficient counting strategy. Count and compare the numerosity of collections of items, using conventional number names and symbols.
	Understand the number system	N	Develop, recognise and work with a flexible conception of zero taking into account multiple meanings that arise in mathematics and 'real-world' scenarios.		Recognise that negative numbers are used in the everyday world around us. Extend the number line model to include zero and negative integers.
	Understand Subitising / Estimating	SE	Be aware of numbers in a range of everyday contexts, recognising associated symbols, words and magnitudes. Estimate sensible counts for sets of a large number of objects.		Estimate and consider the suitability for a variety of measures.
	Understanding Place Value	PV	Partition numbers and use a range of visual representations of numbers to reveal structures.	Use the structure and language associated with the base ten numeration system to partition numbers.	
	Understanding Adding and Subtracting	AS	Consider addition and subtraction in 'change' situations where addition is related to an increase and subtraction to a decrease in quantity, and they are the inverse of each other.	Work confidently with addition and subtraction word problems.	Recognise and use the commutative and associative property of addition.
	Understanding Multiplication and Division	MD			Multiplication and Division as inverse operations; Multiplication as repeated addition / groups / arrays; Division as equal groups / sharing; Division as repeated subtraction

DOMAIN	MAIN CONCEPT	CODE	4	5	6
Number (whole number and 4 operations)	Understand Naming, Conserving, and Counting	C			
	Understand the number system	N		Write natural numbers as a product of two or more factors. Develop awareness of the significance of prime numbers as the 'building blocks' of the natural numbers, recognising that all natural numbers have factors that are prime, and can be expressed as a product of prime factors.	Recognise square numbers and cube numbers in terms of their multiplicative structure, as well as their geometrical representations (area and volume).
	Understand Subitising / Estimating	SE			Round values and measurements to suitable levels of accuracy.
	Understanding Place Value	PV	Recognise the similarities between the structure of the whole numbers and decimals.	Recognise the relationships between large numbers such as billions, millions and trillions. Have a sense of their size with respect to real life objects.	
	Understanding Adding and Subtracting	AS	Using informal written and mental strategies of addition and subtraction.	Develop a sense of how the 'column method' or 'vertical algorithm' may be used as a formal written method for addition and subtraction. Compare and contrast this method with other, informal, written and mental strategies.	
	Understanding Multiplication and Division	MD	Recall multiplicative products and work flexibly with them.	Explore the commutative, associative, summative and distributive properties of multiplication.	Use multiplicative reasoning, the distributive property of multiplication, and known multiplication facts, to solve problems involving multiplication of numbers with one and two digits.

DOMAIN	MAIN CONCEPT	CODE	7	8	9
Number (whole number and 4 operations)	Understand Naming, Conserving, and Counting	C			
	Understand the number system	N	Relate the square root and cube root to a geometrical context and as an inverse relationship.	Use a range of strategies to move between equivalent fraction and decimal representations of rational numbers. Have a sense of different types of decimal numbers that exist (terminating; infinite repeating; and, to a lesser extent, infinite non-repeating) and how they relate (or not) to an equivalent fraction representation. Notice that non-repeating infinite decimals are not generated by fractions; irrational numbers.	Begin to estimate the numerical value of an nth root. Recognise the inverse relationship between powers and roots.
	Understand Subitising / Estimating	SE			
	Understanding Place Value	PV			
	Understanding Adding and Subtracting	AS			
	Understanding Multiplication and Division	MD	Encounter, and recognise strategies to solve, quotitive and partitative division problems.	Develop a sense of how and when more formal written algorithms for multiplication and division may be used. Compare and contrast this method with other written and mental strategies for calculation.	

DOMAIN	MAIN CONCEPT	CODE	FOUNDATION 1	FOUNDATION 2	FOUNDATION 3
Fractions, Decimals & Percentages (and 4 operations)	Understanding Decimal System, Equivalences, and Place Value	DEP			
	Understanding Adding and Subtracting (Decimal)	ASD			
	Understanding Fractions as Parts and Equivalences	FPE			Share a collection of objects into equal groups.
	Comparing Fractions	CoF			
	Understanding Adding and Subtracting (fractions)	ASF			
	Understanding Percentage and Equivalences	PE			
	Understanding Multiplication and Division (Decimal)	MDD			
	Understanding Multiplication and Division (fractions)	MDF			

DOMAIN	MAIN CONCEPT	CODE	1	2	3
Fractions, Decimals & Percentages (and 4 operations)	Understanding Decimal System, Equivalences, and Place Value	DEP		Use manipulatives to develop language of decimals/the base ten numeration system.	
	Understanding Adding and Subtracting (Decimal)	ASD			
	Understanding Fractions as Parts and Equivalences	FPE		Recognise that a number or quantity may be divided into any number of equal 'pieces' that may be described as 1/n of the whole. Know that n of these 'pieces' together represent the original number.	Create and use area models of fractions by partitioning bars, rectangles, and circles.
	Comparing Fractions	CoF			Compare fractions with the same denominator and unit fractions. Decide which is larger or smaller based on reasoning related to division (or sharing) and measurement
	Understanding Adding and Subtracting (fractions)	ASF			Recognise that additive reasoning developed with the counting numbers may be adapted to apply to fractions supported by the use of area and/or linear models. Add and subtract fractions with the same denominator.
	Understanding Percentage and Equivalences	PE			
	Understanding Multiplication and Division (Decimal)	MDD			
	Understanding Multiplication and Division (fractions)	MDF			

DOMAIN	MAIN CONCEPT	CODE	4	5	6
Fractions, Decimals & Percentages (and 4 operations)	Understanding Decimal System, Equivalences, and Place Value	DEP	Position decimals on a number line.		Measure/round to a given number of decimal places.
	Understanding Adding and Subtracting (Decimal)	ASD			Using a sense of place value, to recognise the similarities in the behaviour of counting numbers and decimal numbers. Develop a sense of how the 'column method' or 'vertical algorithm' may be used as a formal written method for addition and subtraction. Compare and contrast this method with other, informal, written and mental strategies.
	Understanding Fractions as Parts and Equivalences	FPE	Recognise that a fraction has multiple meanings and may be interpreted and represented in a variety of ways, including division and proportion.		
	Comparing Fractions	CoF	Position fractions between 0 and 1 on an empty number line.	Compare fractions with different denominators using a variety of strategies, such as using benchmark values, the size of denominator, area and linear models	Recognise simple examples of equivalent fractions, understanding that equivalent fractions are equal in size (for example, they are located at the same position on a number line, represent the same area in a bar diagram, and so on).
	Understanding Adding and Subtracting (fractions)	ASF			Add and subtract fractions with related denominators (one a multiple of the other).
	Understanding Percentage and Equivalences	PE	Connecting the notion of percentage to experiences with fractions, particularly those with denominators of 100. Explore a range of contexts, problems, and representations that	Relate percentage knowledge for "special" values such as: 50%; 25%; 100%; 75%; and 10% to their	Working with benchmark values such as 10%, 25%, 50%, and recognise how to compose other proportions from these, reinforcing the

			involve a notion of 'parts-per-hundred'.	fractional equivalents. Find these proportions of amounts.	connections to fractional representations of proportion.
	Understanding Multiplication and Division (Decimal)	MDD			
	Understanding Multiplication and Division (fractions)	MDF			

DOMAIN	MAIN CONCEPT	CODE	7	8	9
Fractions, Decimals & Percentages (and 4 operations)	Understanding Decimal System, Equivalences, and Place Value	DEP	Compare decimals in a variety of contexts (such as length, currency, and part-whole fractional reasoning), using a variety of strategies including place value structures and equivalence with fractions with denominators of 10 or 100. .		Move between representations of fractions, ratios, decimals and percentages to develop efficient strategies for calculation, comparison, and estimation of proportions.
	Understanding Adding and Subtracting (Decimal)	ASD			
	Understanding Fractions as Parts and Equivalences	FPE	Find simple fractions of a quantity.		
	Comparing Fractions	CoF	Recognise that there are an infinite number of equivalent fractions for any given value and identify the simplest form (the one for which the numerator and denominator have no common divisors). Identify and generate equivalent fractions. Compare fractions using equivalent fractions (where necessary).	Develop strategies to move from fractions to decimal and percentage representations of proportion.	Recognising that fractions are not restricted to values between 0 and 1. Recognise and interpret improper fractions, knowing that any number, including integers, may be written as a fraction in different ways.
	Understanding Adding and Subtracting (fractions)	ASF	Add and subtract proper fractions in a variety of contexts.		Work flexibly with addition and subtraction with rational numbers.
	Understanding Percentage and Equivalences	PE	Recognise that 1% is 100 times smaller than the 'whole' quantity (or 100%), 1/100th. Use the 1% value, combined with other benchmarks or scaled to directly calculate the required proportion.	Find equivalent fractions and decimals to given percentages. Move between percentage, fraction and decimal representations of benchmark values such as 0.5, 0.1, 0.25, 0.75, 1 and so on.	Move flexibly between, ratio, fraction, decimal and percentage representations of proportion in order to facilitate comparison of two or more proportions.
	Understanding Multiplication	MDD		Recognise that multiplication with decimal numbers extends from the same	Use a variety of strategies for interpreting, representing and calculating

	and Division (Decimal)			patterns, 'rules' and strategies as that with integers.	multiplication and division of decimal numbers by whole numbers.
	Understanding Multiplication and Division (fractions)	MDF			Begin to explore situations in which quantities are successively partitioned, for example taking a half of a half. Encounter and explore problems related to division with fractions given in (non-mathematical) contexts. Know a variety of strategies for evaluating problems involving multiplication or division of fractions.

DOMAIN	MAIN CONCEPT	CODE	FOUNDATION 1	FOUNDATION 2	FOUNDATION 3
Geometry	Shape	Shp	Develop familiarity with and identify (as a whole) 2D and 3D shapes, without relying on properties.	Identify simple properties of 2D and 3D shapes such as number of edges, equality of edges.	
	Position-Space	P-S		Informally record routes through the immediate environment.	Work with, describe and design plans of relative position for objects in view.
	Symmetry and Isometric transformations	SIT			Recognise reflections and shapes with reflectional symmetry. Recognise rotated shapes and shapes with rotational symmetry. Recognise translated shapes and patterns with translational symmetry.
	Constructions	Con		Use practical equipment to reproduce and produce pictures and mathematical shapes in 2D	
	Congruent and similar shapes	C&S			
	Pythagoras	Pyt			

DOMAIN	MAIN CONCEPT	CODE	1	2	3
Geometry	Shape	Shp	Recognise, define and construct a circle.	Identify right angles, parallel and perpendicular lines and faces in 2D and 3D shapes.	Describe properties of 2D shapes in terms of symmetrical properties, equality of angles and side lengths. Recognise and identify 2D shapes using the above properties.
	Position-Space	P-S	Work with a variety of representations of the immediate environment		Work with plans and maps that use 'addresses'
	Symmetry and Isometric transformations	SIT		Predict and check practically the position of mirror lines/lines of symmetry and the order of rotation of 2D shapes. Identify the implications of having mirror or rotational symmetry in terms of congruency of sides and angles.	Identify lines of symmetry and rotational symmetry in a given pattern or shape. Describe the symmetrical properties of special triangles, quadrilaterals, regular polygons and circles with diagrams or through visualising the shape.
	Constructions	Con	Copy and sketch shapes and simple patterns freehand or using geometrical units (edges, angles). Investigate the properties of constructed shapes.	Recognise that 2D material can be used to make 3D objects, some easier than others.	Compose, decompose and recompose 3D objects and shapes from 3D shapes.
	Congruent and similar shapes	C&S	Identify, informally, similarities and differences between sets of pictures, shapes or objects. Identify, informally, similar rectangles and pairs of lines, such as 'fat' versus 'skinny' or 'wide' versus 'tall' rectangles		Identify congruent lengths and angles by overlaying. Identify congruent lengths and angles from the symmetrical properties of shapes. Identify congruent shapes; recognising that they have congruent angles and congruent side lengths.
	Pythagoras	Pyt			

DOMAIN	MAIN CONCEPT	CODE	4	5	6
Geometry	Shape	Shp	Describe properties of 3D shapes in terms of faces, equality of faces/edges, and cross-sections. Recognise and identify 3D shapes using the above properties.	Analyse properties of 2D shape, consider the hierarchy and family links between shapes.	
	Position-Space	P-S	Work with Cartesian co-ordinates	Connect various symbolic representations to a position and line of sight on a map or plan.	Identify and draw plans and elevations of 3D objects. Identify 3D objects from their plans and elevations.
	Symmetry and Isometric transformations	SIT	Reflect simple patterns and shapes on paper. Rotate simple patterns and shapes on paper, with no centre or with a centre on one vertex of the pattern or shape, in multiples of quarter turns.	Identify repeating patterns in culturally appropriate contexts. Identify reflections, glide reflections, rotations, and translations in these patterns using informal explanations.	Identify tessellating patterns or tilings, the tessellating/tiling unit/s, including a lattice structure and its geometrical properties. Identify, describe, carry out and analyse translations (including identifying the non-existence of invariant points) expressed in words.
	Constructions	Con		Investigate the variety of configurations possible using lines and circles on a plane. Identify these configurations in more complicated diagrams. (Investigate the variety of configurations possible using three lines in 3D)	Copy and construct shapes/patterns accurately on dotted or lattice paper. Reproduce circle diagrams from drawn examples or written instructions. Label vertices, edges and angles accurately.
	Congruent and similar shapes	C&S			Draw and investigate the properties of enlargements of pictures on sheared grids, stretched grids, and enlarged grids.
	Pythagoras	Pyt			

DOMAIN	MAIN CONCEPT	CODE	7	8	9
Geometry	Shape	Shp	Define triangles; recognise necessary and sufficient conditions. Identify with respect to definitions examples and non-examples.	Define quadrilaterals; recognise necessary and sufficient conditions. Identify with respect to definitions examples and non-examples.	
	Position-Space	P-S	Design accurate instructions to reproduce a given or desired path/route from direct experience, memory or on a map.	Draw and interpret floor plans using simple scales	Work with simple compass directions and their shorthand. Work with simple relationships on a Cartesian co-ordinate grid.
	Symmetry and Isometric transformations	SIT	Identify, describe, carry out and analyse reflections (including identifying invariant points) in vertical or horizontal mirror lines or those at 45 degrees including those expressed symbolically.	Identify, describe, carry out and analyse rotations (including identifying invariant points), finding the centre of rotation by trial and error.	Identify, describe, carry out and differentiate between rotation, reflection and translation, on a cartesian plane as well as on plain paper. Carry out combined transformations.
	Constructions	Con	Use 2D shapes to construct 3D shapes, including with and without instructions in a variety of formats and examples to examine and/or disassemble. Measure and calculate the surface area of cuboids and simple prisms.		Compose, decompose and recompose triangles and quadrilaterals to form triangles or rectangles. Consider the effect of decomposing and recomposing on area, perimeter and the dimensions of the shapes concerned.
	Congruent and similar shapes	C&S	Recognise the relationship between the co-ordinates of an object and its image under enlargement (anchor or centre at the origin). Consider what remains invariant in such a transformation. Construct enlargements of objects given an anchor or centre and scale factor.	Identify the necessary conditions to construct a triangle using a straight edge and compass, and situations where instructions are ambiguous. Recognise that the necessary conditions to construct a triangle offer an opportunity to assess the congruency of two (or more) triangles. Establish the congruency axioms. Use angle axioms, congruency axioms, and/or symmetrical properties to prove the implications of properties of special triangles. Use angle and congruency axioms or isometric transformations to prove the congruence of triangles.	Recognise the equality of ratios between corresponding sides in objects and their images or of a pair of sides in an object and the corresponding pair in an image when enlarged (similar). Calculate scale factors or missing sides on similar shapes by counting, measuring or using given dimensions/co-ordinates, in multiple contexts. Identify examples and non-examples of similar shapes, in multiple contexts.

	Pythagoras	Pyt	Decompose shapes in multiple ways to find their areas.	Derive the Pythagorean relationship between the area of the squares on each side of a right-angled triangle.	Consider the relationships of obtuse, acute and right-angle triangles and squares on their edges. Use these relationships to show or disprove if a given triangle is right angled. Use Pythagoras' theorem to find missing edges in right angled triangles, including embedded in other structures.

DOMAIN	MAIN CONCEPT	CODE	FOUNDATION 1	FOUNDATION 2	FOUNDATION 3
Measure	Length	Len	Begin to identify and compare the measurable attributes of objects. Identify, compare and order by length. Carry out simple logical deductions concerning length.	Identify paths; tracings of the movement of a point, including straight and curved paths. Compare the lengths of paths using an interim tool such as string. Recognise that paths with matching start and end points may not be the same length and that the shortest path between the start and end is a straight line (distance). Identify the perimeter of any given shape	Pace off or count lengths, paths and perimeters
	Area	Are			Begin to identify and compare the measurable attributes of objects. Identify areas. Compare areas: predict, justify and confirm practically whether one is larger, smaller or equal to another. Carry out simple logical deductions concerning area.
	Volume/ Capacity	Vol			Begin to identify and compare the measurable attributes of objects. Identify, compare and order by volume. Carry out simple logical deductions concerning volume.
	Angle	Ang			
	Weight	Wei			
	Time	Tm			Use appropriate language of units of time (days, years, minutes) , the order of events (before later, after), the length or rate of events (longer, shorter, quicker, slower, days of the week, months, seasons to describe everyday events.

DOMAIN	MAIN CONCEPT	CODE	1	2	3
Measure	Length	Len	Construct and use a measuring stick using a non-standard unit. Estimate and measure lengths, in centimetres or metres (to required level o accuracy), using a variety of equipment.		
	Area	Are		Compare the area a shape covers by 'pacing off', using an interim (arbitrary) measure. Develop a sense of suitable units to use to measure area and need for a consistent measure. Find lower and upper bounds for the area of a shape in a given unit.	Pace off areas by enumerating units in an array. Develop a logical enumeration of units in an array, spotting patterns within the numbering. Decompose a rectangular array into units. Develop a sense of square centimetres and metres as a unit of area. Estimate and find the area of shapes by pacing off in square centimetres or metres.
	Volume/ Capacity	Vol	Compare the volume of an object by 'pacing off', using an interim (arbitrary) measure. Develop a sense of suitable units to use to measure volume and need for a consistent measure. Find lower and upper bounds for the volume of an object in a given unit.		Pacing off the volume of a cuboid through stacking cubes, including cube centimetres. Identify the dimensions of a cuboid from a model or 2D representation. Decompose a 3D cuboid array into units.
	Angle	Ang	Identify and compare angles including those in bends and slopes, predict, justify and confirm practically whether one is larger, smaller or equal to another. Carry out simple logical deductions concerning angles.	Identify, label accurately, name and draw (not specific measures) acute, obtuse and reflex angles in a variety of contexts.	Compare physical angles in the surrounding environment by 'pacing off', using an interim (arbitrary) measure. Develop the degree as a unit of measure for angles.
	Weight	Wei	Begin to identify and compare the measurable attributes of objects. Compare weight: predict, justify and confirm practically whether one is heavier, lighter, or equal to another; using a balance scale. Carry out simple logical deductions concerning weight.	Compare weight: predict, justify and confirm practically whether one is heavier, lighter, or equal to another by measuring the stretch of a spring. Carry out simple logical deductions concerning weight.	Pacing off weight through using an interim measure and a balance scale.
	Time	Tm	Sequence familiar events and activities. Compare the lengths of familiar events.	Pacing off time through hand claps or counting.	Work with minutes, hours and common fractions of an hour.

DOMAIN	MAIN CONCEPT	CODE	4	5	6
Measure	Length	Len	Identify and use the correct measuring tool, and therefore unit, to measure angle, length or volume. Be familiar and have a sense of (benchmarks) the units of cm and m, use these to judge the validity of a measured value. Estimate and measure the length of a path, including perimeters of polygons and the (shortest) distance between two points. Investigate the effect of zooming in on a ruler on the structure of the measuring tool; including scales of none-unit steps. Identify the dimensions of a rectangle. Identify the dimensions of a cuboid from a model or 2D representation.		Use the meaning of kilo, hect, dec, deci, centi and mili to convert between metric units of length. Recognise suitable situations for the variety of units and establish benchmarks for each unit. Combining a variety of length measurements in a variety of units.
	Area	Are	Use a logical enumeration of an array to develop an efficient strategy to find the total number of unit squares. Develop and work with the formula (ab=c) to solve problems involving the area of a rectangle in multiple situations.		Calculate, with explanation, how many square centimetres in a square metre. Convert between units before and after calculating areas.
	Volume/ Capacity	Vol	Develop and use a volume measuring tool to compare volumes and recognise the effect the shape of the container has on any scale. Estimate and measure volumes in litres.		
	Angle	Ang	Identify, label accurately, estimate and measure angles including those caused by rotation/turn, turn in a path or a slope, using a 360˚ moving arm protractor.	Deduce missing angles using the axioms of angles meeting at a point and angles meeting along a straight line. Use the axioms of angles meeting at a point and angles meeting along a straight line, to deduce whether a set of angles form such structures. Investigate the relationship of vertically opposite angles. Give an argument to explain the equality of vertically opposite angles.	Measure, demonstrate and justify the triangle angle rules.

	Weight	Wei	Construct and use a measuring scale using a spring and non-standard unit. Develop and use the standard unit of kilogram (discussion of weight vs mass to follow in science).		
	Time	Tm	Work with cyclical number and nature of days of the week, and days in a month, to calculate time intervals in days. Estimate and measure the time of events or activities. Give sensible estimates for longer activities.	Read and write time in a digital and analogue representation.	Move between three representations of recorded time; in words, digital and analogue representations.

DOMAIN	MAIN CONCEPT	CODE	7	8	9
Measure	Length	Len	Recognise the existence of other scientific units and other systems of measurement and how they have been developed. e.g. cubit, foot, yard, chain, block, meaning of imperial, inch, yard etc. Investigate non-metric units of measurement using historic and cultural links. Develop a sense of benchmarks for important common non-metric units and their conversions. Use circles to identify points less than, exactly or more than a specified distance from a given point or points.	Calculate paths, including perimeters, by counting on a grid where a scale has been given and on diagrams with labelled lengths. Calculate missing lengths of squares, rectangles, rectilinear shapes, and regular polygons, in order to find their perimeter. Calculate perimeters of quadrilaterals and regular polygons using efficient methods. Design quadrilaterals and regular polygons with given perimeters.	By repeated measurement investigate the relationship between the radius and circumference of a circle. Solve problems involving the circumference of a circle, arc length or rotations.
	Area	Are	Investigate the effect of decomposing and recomposing, and shearing shapes on their area and perimeter. By decomposing and recomposing and/or shearing find the area of a parallelogram. Solve problems involving the area of a parallelogram in multiple situations. By relating a triangle to a parallelogram find its area. Solve problems involving the area of a triangle in multiple situations.	Calculate areas of compound shapes (composed from rectangles, parallelograms, and triangles) drawn to scale, from diagrams/descriptions, including a mixture of units, and drawn or expressed as co-ordinates on a co-ordinate grid. Design compound shapes with given areas. Present solutions drawn to scale, in diagrams/descriptions, including a mixture of units, drawn or expressed as co-ordinate on a co-ordinate grid. Decompose quadrilaterals to develop methods to find their areas. Identify the required measures in order to calculate their areas. Solve problems involving the area of quadrilaterals in multiple situations.	Counting units to find an approximation, upper and lower boundaries, for the area of a circle. Find the area of a circle in terms of its radius and circumference. Develop the formula for the area of a circle. Solve problems involving the area of a circle and fractions of a circle in multiple situations. Recognise the existence of other systems of measurement and how they have been developed. Investigate non-metric units of measurement using historic and cultural links. Develop a sense of benchmarks for important common non-metric units and their conversions.
	Volume/ Capacity	Vol	Finding volumes of given shapes by counting cubes from isometric drawing, in a DGE and physical models, including those with hidden cubes. Use a logical enumeration of a 3D array to develop an efficient strategy to find the total number of unit cubes. Develop and work with the formula (abc=d) to solve problems	Use the meaning of kilo, hect, dec, deci, centi and mili to convert between metric units of volume (in units cubed). Use the meaning of kilo, hect, dec, deci, centi and mili to convert between metric units of volume concerning litres. Recognise suitable situations for the variety of units and establish benchmarks for each unit. Compare and convert between cubic	Identify, with reason, everyday objects that examples or non-examples of prisms or cylinders. Identify the cross-section and height (or width) of any given prism or cylinder, recognising that they are at right angles to each other. Consider the relationship between the cross-sectional area and a 'slice' of the prism 1 unit in width, and therefore the prism or

			involving the volume of a cuboid in multiple situations.	metric units to litres and derived units of volume measurement. Recognise suitable situations for the variety of units. Recognise the existence of other systems of measurement and how they have been developed. Investigate non-metric units of measurement using historic and cultural links. Develop a sense of benchmarks for important common non-metric units and their conversions.	cylinders volume. Estimate and find the volume of various prisms or cylinders; find the cross-sectional area, through calculation or counting squares in a trace, and measure their height. Develop and work with the formula (volume = cross sectional area x height) to solve problems involving the volume prisms and cylinders (including in cubed cm and m) in multiple situations and representations, including models, 3D co-ordinates, isometric drawings, plans and elevations, and nets.
	Angle	Ang	Construct and label angles using a protractor. Follow instructions to construct and label simple shapes including the use of a ruler, compass and protractor, recognise when and where any ambiguity lies.	Work with angles in triangles. Investigate invariant angle relationships in parallel lines. Deduce angles in parallel lines. Prove the sum of internal angles of a triangle is 180 degrees.	Investigate invariant angle relationships in quadrilaterals. Deduce angles in quadrilaterals. Investigate angle relationships in polygons. Deduce angles in quadrilaterals.
	Weight	Wei	Use the meaning of kilo, hect, dec, deci, centi and mili to convert between metric units of mass concerning grams. Recognise suitable situations for the variety of units and establish benchmarks for each unit. Combining a variety of mass measurements in a variety of units.	Recognise the existence of other systems of measurement and how they have been developed. Investigate non-metric units of measurement using historic and cultural links. Develop a sense of benchmarks for important common non-metric units and their conversions.	
	Time	Tm	Working with time intervals in hours and minutes in digital and analogue representations.	Calculating time intervals in minutes, hours, days and months, represented on the 12 hour and 24-hour analogue clock and the digital clock, and through calendar.	Working with a variety of representations of time, for example; timetables, schedules, timelines, different types of clocks, structure of calendars, sundials, numbered/not numbered clocks, Corpus clock egg timers, and other culturally relevant representations.

DOMAIN	MAIN CONCEPT	CODE	FOUNDATION 1	FOUNDATION 2	FOUNDATION 3
Algebra working and thinking	Equivalence	EQ			
	Inequalities	INQ			
	Relationships + Functions	RF			
	Patterns + Functions	PF			
	Change + Functions	CF			

DOMAIN	MAIN CONCEPT	CODE	1	2	3
Algebra working and thinking	Equivalence	EQ	Understand that two quantities can relate in one of three ways: they can be equal, one quantity can be larger than the other, or one quantity can be smaller than the other (Trichotomy Property)	Use the equal sign to represent equivalent relationships between quantities and / or numerical (or symbolic) expressions.	Recognise that for quantities a, b and c: if $a = b$, then $b = a$; if $a = b$ and $b = c$, then $a = c$ (the transitive property).
	Inequalities	INQ	Recognise that adding or subtracting the same quantity to both sides of an inequality ($>, \leq, \geq$ and $\neq$) relationship preserves the equivalence.	Recognise the reasoning that for quantities a, b, and c: if $a < b$ and $b < c$, then $a < c$ if $a \leq b$ and $b \leq c$ then $a \leq c$ (the transitive property)	Recognise the effect of multiplying or dividing both sides of an inequality ($>, \leq, \geq$ and $\neq$) relationship by the same positive quantity.
	Relationships + Functions	RF	Explore practical examples of corresponding values in a relationship without generalising and how to represent them.	Begin to generalise functional relationships verbally and using early symbolic language; identifying the mathematical transformation between the quantities, such as every cat has two eyes, or the constraint linking them, such as the total of heads and tails has to be 10 (explicit and implicit functions)	Explore how to represent number sequences or relationship between two variables, produced in multiple contexts, using ordered pairs, tables, points on a Cartesian graph, and verbal descriptions.
	Patterns + Functions	PF			Work with geometric patterns; as a sequence of specific instances and generalise the rule between successive terms.
	Change + Functions	CF			

DOMAIN	**MAIN CONCEPT**	**CODE**	**4**	**5**	**6**
Algebra working and thinking	Equivalence	EQ	Recognise that adding or subtracting the same quantity to both sides of an equivalence relationship (= and ≠) preserves the equivalence.	Recognise that multiplying or dividing both sides of an equivalence relationship (= and ≠) by the same nonzero quantity preserves the equivalence. Recognise the effect of multiplying or dividing both sides of an equivalence relationship (= and ≠) by zero has on the equivalence.	
	Inequalities	INQ	Recognise the effect of multiplying or dividing both sides of an inequality (>, ≤, ≥ and ≠) relationship by the same negative quantity.		
	Relationships + Functions	RF	Explore the different ways to operate on a number to get from one to another. Develop recognition of additive, multiplicative and multi-step processes.	Identify (examples and non-examples), describe, represent and work with directly proportional relationships using tables, cartesian co-ordinates and algebraic representations, in a variety of contexts (explicit and implicit functions). Recognise contexts when it is appropriate to join co-ordinates to produce a graph.	Use multiple representations to solve direct proportion problems and 1-step multiplicative equations and inequalities, including symbolic manipulation.
	Patterns + Functions	PF	Continue number patterns, such as two, four, six, eight and begin to generalise the term to term rule (in words)		
	Change + Functions	CF			Sketch and investigate graphs that describe movement over time. Describe movement represented in a sketched graph.

DOMAIN	MAIN CONCEPT	CODE	7	8	9
Algebra working and thinking	Equivalence	EQ			
	Inequalities	INQ			
	Relationships + Functions	RF	Work with multiple directly proportional relationships using tables, cartesian co-ordinates and algebraic representations, in a variety of contexts (explicit and implicit functions). Use representations to solve comparative or simultaneous multiplicative problems.	Identify (examples and non-examples), describe, represent and work with linear relationships using tables, cartesian co-ordinates and algebraic representations, in a variety of contexts including as describing position on a Cartesian plane. Recognise contexts when it is appropriate to join co-ordinates to produce a graph.	Use multiple representations to solve linear equations and inequalities, including symbolic manipulation maintaining equivalence.
	Patterns + Functions	PF			
	Change + Functions	CF	Work flexibly with graphs of physical situations considering specific data points, general patterns and relationships without carrying out numerical calculations.	Work flexibly with graphs of physical situations considering specific data points, general patterns and relationships. Consider what rates or compound units can be identified from the graphs, paying attention to the units being used.	Work flexibly with graphs of physical situations, compound measures and rates to solve problems in a variety of contexts.

DOMAIN	MAIN CONCEPT	CODE	FOUNDATION 1	FOUNDATION 2	FOUNDATION 3
Data handling	Understanding and working with data.	UWD			Identify variables that allow objects to be treated as data, e.g. colour, height, number of siblings.
	Considering data distribution variability measure and representations.	DVM			
	Working with time series and bivariate data	TSB			
Risk	Using probability to understand issues of risk.	P&R			

DOMAIN	MAIN CONCEPT	CODE	1	2	3
Data handling	Understanding and working with data.	UWD	Systematically organise objects/phenomena in response to questions that arise from a motivating context, e.g. lists and tables	Design strategies for collecting and recording data from small, finite populations. Design convenience strategies for collecting and recording small samples of data from larger populations. Draw informal inferences from data organised systematically, including simple tables of multivariate data. Critique inferences drawn from data organised systematically	Order and sort and group data by category and create visual representations both formal and informal. Select appropriate visual representations and use them to gain insight into contextual questions that arise.
	Considering data distribution variability measure and representations.	DVM			Recording and representing data to highlight distribution, location and spread
	Working with time series and bivariate data	TSB			
Risk	Using probability to understand issues of risk.	P&R		Understand that likelihood is related to how frequently an event occurs and interpret experimental data in this context. Recognise situations that are random in nature.	

DOMAIN	MAIN CONCEPT	CODE	4	5	6
Data handling	Understanding and working with data.	UWD	Consider a range of possible measures to capture important aspects of an object or phenomena	Select appropriate measures based on consideration of reliability, replicability, and accuracy to answer questions in a motivating context.	Organise and represent quantitative data both formally and informally in order to gain insight into contextual questions that arise.
	Considering data distribution variability measure and representations.	DVM	Describe data using mode and subjective description of variation, and know when it is appropriate to use these measures.	Describe data using median, range, and interquartile range, and know when it is appropriate to use these measures.	Describe data using mean and subjective description of variation, and know when it is appropriate to use these measures.
	Working with time series and bivariate data	TSB	Plan to capture and record time-series data systematically and carefully. Represent, describe and interpret time-series data, communicating trends and relationships	Plan to capture and record bivariate data systematically and carefully. Represent, describe and interpret bivariate data, communicating trends and relationships	Select appropriate scales in order to emphasis relationships and trends in time-series and bivariate data
Risk	Using probability to understand issues of risk.	P&R	Calculate probabilities based on experimental results as the proportion of the result for a specific outcome given a sufficiently large number of trials	Calculate theoretical probabilities based on the structure of a sample space as the proportion of the sample space for a specific outcome	

DOMAIN	MAIN CONCEPT	CODE	7	8	9
Data handling	Understanding and working with data.	UWD	Draw distinctions between discrete and continuous data and the implications for representation	Organise data into groups in order to facilitate understanding of data, considering the implication of choices such as group widths, and whether class widths are equal or unequal. Represent grouped data both formally and informally, taking into account the effect of data type, in order to gain insight into contextual questions that arise.	Consider different types of data and how their type affects the ways in which they can be represented and how this can help them make sense of the world. Be aware that the type of data restricts viable ways in which it might be used and represented. Take a critical stance when presented with data and ask questions such as "is the data representation likely to accurately represent the phenomenon being investigated - is anything excluded that shouldn't be? - does the representation overstate the case?
	Considering data distribution variability measure and representations.	DVM	Describe data using measures of centre and spread appropriate to the data and the contextual question motivating exploration.	Use appropriate measures of location and spread as well as representations of distributions to interpret and make comparisons between data sets to answer questions that arise from motivating contexts	Identify and select appropriate measures that insight into data distribution and use these to describe, compare and contrast data sets (including comparing over time)
	Working with time series and bivariate data	TSB	Identify underlying patterns in data, considering positive and negative correlation. Understand the difference between correlation and causation and consider the implications of possible third factors	Model time-series data and correlated data using straight lines. Consider the validity of straight-line models with regard to the shape, spread, and accuracy of the data being modelled. Be able to represent data that has been collected over appropriate time intervals and work with time-series representations (including informal representations such as timelines)	Be able to interpret and where possible model data so as to be able to make inferences and predictions. Differentiate situations where apparent correlation can be used to identify causation form those where this is not the case.
Risk	Using probability to understand issues of risk.	P&R	Calculate expected frequencies using theoretical probabilities and understand that this is a useful model only when the total number of trials is sufficiently large. Compare experimental and theoretical results and identify deviations that may indicate bias	Organise data (and theoretical outcomes) in representations such as sample spaces and two-way tables. Use such diagrams to make sense of situations that involve independent events. Use representations of data to provide insight into relative frequencies and probabilities. Including using representations as models to make predictions and decisions.	Critically explore claims made using data and probability, for example reports of risk. Understand probability as an expression of the actual or predicted frequency of an event and use probability to make critical judgements of risk.

5 Science framework development

The Science framework development began after the Maths framework development was already in progress. Therefore, the Science development benefited from drawing on the work that had already been completed by the Maths framework development team.

5.1 Stage S1: Process of defining the subject framework principles and parameters

To define the Science framework development principles and parameters a thorough review of relevant research, expert consultation and international approaches to Science curriculum was conducted. In addition to the development principles outlined in Table 2, the Research and Recommendations report (Cambridge University Press & Cambridge Assessment, 2020) provided four key development recommendations for a Science curriculum framework:

1. The framework should be contextually-agnostic and knowledge focused.
2. Terminology should be carefully chosen, and key definitions should be provided.
3. Space for practical elements should be integrated, but not specifically defined.
4. The framework should enable space for indigenous knowledge integration.

These development principles (Table 2) and recommendations (above) were at the foundation of the development method for the Science framework.

To satisfy the first recommendation above and the fourth development principle in Table 2, it was decided by the curriculum development team that the Science framework would focus on the core disciplinary knowledge that transcends cultural and regional contexts. This also aligns with the importance of Powerful Knowledge (Young, et al. 2014) which was a key theory underpinning the Learning Passport project (see section 2.1.1). This focus on knowledge does not mean that the development team believes knowledge is the most important element of Science education. Rather, the team recognised that scientific knowledge as well as the practical application of this knowledge are both vital components when educating learners in the discipline of science. In many curricula around the world, the involvement of practical work is a central component of Science education (Abrahams & Millar, 2008). Coherent knowledge-based learning sequences integrated with authentic practical application supports high quality science education and moves learners away from rote memorisation of scientific facts (Wellington & Ireson, 2017). However, due to the context factors and material dependency of specific practical activities, it was decided that the integration of practical activities should be decided by education specialists at the local or regional level. This will ensure that the practical activities have direct connection and value to the learners and that they will have the appropriate resources and environment in order to conduct these practical activities effectively and successfully. Therefore, the framework will be structured around the core disciplinary knowledge, but with the acknowledgement that practical elements will be integrated when the framework is expanded into a curriculum at the local or regional level. This also supports development principle four, by being context-agnostic, and principle five, by not relying on resource availability (Table 2).

Once the decision was made that the framework would focus explicitly on the core disciplinary knowledge of Science, the development team had to decide how core disciplinary knowledge would be defined in order to devise a method to later distil this knowledge from the broader scientific discipline. In comparison with Maths, the disciplinary knowledge taught in primary and secondary Science education varies greatly around the world. In many contexts, the science curriculum is a contested terrain, with multiple aims and stakeholders competing with one another with different views of best practice (Blanco-Lopez, Espana-Ramos, Gonzalez-Garcia & Franco-Mariscal, 2015; Fensham, 2009, 2013; Ryder and Banner, 2011). A science curriculum can vary based on the regional and cultural environment in which it is taught, as well as the resources available to learners. In order to ensure that the framework can support a variety of regional and cultural environments, regardless of the resources available, the framework should include only the core, transnational learning concepts. Like Maths, it would need to serve as a boundary object (Gasson, 2005; Wenger-Trayner, Wenger-Trayner, Cameron, Eryigit-Madzwamuse, & Hart, 2019). In addition, it was recognised that this curriculum framework should also support reintegration of the learner into a formal education jurisdiction in the future. Therefore, some consideration should be given to the common themes and approaches to Science education, especially in areas of high displacement considering this framework is being designed for displaced learners. This also links to a key development principle (Table 2), which states that the framework should support potential re-integration of all learners.

To ensure that the framework is consistent with current best practices in science education and to ensure that the framework could be used across a variety of contexts, various international approaches to science education were considered. The process of considering international approaches involved two elements. First, a curriculum mapping was conducted focusing on relevant curricula and second, internationally recognised science frameworks were analysed for structure and content.

5.1.1 Curriculum and framework mapping

Due to the diversity in content and approaches to Science curricula around the world, the curriculum mapping exercise was conducted in order to assess what concepts and content are included in leading and relevant Science curricula. Several decisions contributed to deciding which curricula should be considered relevant. Relevant curricula in this project involved two groups of curricula.

Firstly, like Maths, it was decided to include High Performing Jurisdictions (HPJs) in the subject of science in order to provide an empirical basis for what knowledge to include in the learning sequences to support quality learning programme. This satisfies the first development principle which states that the framework should support progress in the subject area (Table 2). Although there are many factors when considering whether a jurisdiction is high performing which go beyond curriculum documentation such as approaches to assessment and allied social measures (Oates, 2017), it can be inferred that the curriculum used by a HPJ is of considerable quality in addition to several contextual factors that create an optimal learning environment.

The HPJs included in the mapping were chosen based on the 2015 PISA Science results tables (OECD, 2019). The HPJs chosen were Hong Kong, Finland and Singapore. Based on the 2015 PISA Science results, Hong Kong was ranked 9th, Finland was ranked 5th and Singapore was ranked 1st (OECD, 2019). Of the top ten HPJs, a full curriculum which showed relatively detailed progressions was publicly available for only these three jurisdictions. More curricula could have been considered if they had been publicly available for analysis.

In addition to HPJs, it was also decided to select several Jurisdictions of High Displacement (JHDs) in the curriculum mapping, a concept developed through this project. These jurisdictions are particularly relevant for this framework development since one of the primary aims of the curriculum framework is to enable learners to access the content and skills that enable them to engage in the society in which they might find themselves and in any further education opportunities that they may encounter. In order to select jurisdictions of particular relevance for refugee and displaced learners, we referred to the UNHCR's Global Trends: Forced Displacement in 2018 Report (UNHCR, 2018) which provides an overview of areas of concern to UNHCR. The term displacement/displaced referred to in this list pertains to a variety of groups including refugees, including persons in refugee-like situation; asylum seekers; IDPs (internally displaced peoples) of concern, including persons in an IDP-like situation; returned refugees and IDPs; stateless people and others emerging displaced groups from environmental, political or cultural events. The document listed approximately 30 countries of high displacement. However, only curricula from nine of these countries could be included in the mapping.

To locate these curriculum documents, detailed internet searches were conducted including searching through Ministry websites and the UNESCO IBE curriculum library. In some instances, curriculum documents were also located by searching peer-reviewed academic articles. In addition, colleagues in Cambridge Assessment were consulted to see if recent curriculum documents had been collected for other curriculum development processes.

Unfortunately, it was not possible for the research team to locate original versions of curriculum documents in accessible languages for all jurisdictions named by the UNHCR. However, nine science curricula were located and were included in the mapping. These jurisdictions were Bangladesh, Chile, Cote D'Ivoire, Pakistan, Lebanon, Myanmar, Turkey, South Sudan and Thailand.

There are several limitations associated with this method of collecting curriculum documents. For example, curriculum documents collected may not be the most relevant or up to date documents. Curriculum documents that have been translated may lose some of their original meaning. In addition, it is unclear whether the curriculum documents that we consulted are uniformly applied across the jurisdiction or if there is divergence based on regional or cultural beliefs. Furthermore, assessment documents were not available, so it is unclear what skills and knowledge are summatively assessed. In addition, it is not clear what level of mastery is required of concepts mentioned in the curriculum. We also did not consider textbooks, which may be more central to communicating the curriculum in certain jurisdictions (Pepin, Gueudet & Trouche, 2013). These challenges are common when completing a transnational mapping exercise such as this (Elliott, 2014).

After the curriculum documents were collected and before the curriculum mapping exercise was conducted, efforts were taken to mitigate these limitations. For example, a comparison was completed to show when children in each region begin schooling and the age equivalency for each grade/level (Figure 6). This provided deeper insight into how the learning of science compares across these differing jurisdictions. Due to several variables (e.g. school year length and term times, broader age flexibility for beginning school, the cultural norms surrounding children repeating levels due to failed standardised tests, etc.) this comparison is only an approximation.

Figure 6 Excerpt from the International comparison: Age and School Year

International Comparison: Age and School Year

Colour Key: Blues (primary); Greens (secondary), lighter/darker pertains to jurisdictions that stipulate lower/upper schools.

	Iraq	Italy	Jordan[8]	Lebanon[9]	Myanmar[10]	Nigeria	Pakistan[11]	Philippines[12]
Age	School year	School Year	School year	School year	School year	School year	School Year	School year
5	Preschool (not compulsory)	Nursery (not compulsory)			1	Pre-primary	Pre-school (not compulsory)	
6	1	1	1	1	2	1	1	1
7	2	2	2	2	3	2	2	2
8	3	3	3	3	4	3	3	3
9	4	4	4	4	5	4	4	4
10	5	5	5	5	6	5	5	5
11	6[13]	6[14]	6	6	7	6[15]	6	6
12	7	7	7[16]	7[17]	8	7	7	7
13	8	8	8	8	9	8	8	8

After the age/level comparison was considered, the mapping team undertook a high-level mapping exercise to examine the Discipline/Topic approach to Science taken by each jurisdiction (see Figure 7). This was done in order to provide insight into the various ways that Science curricula are organised which could be done by themes, by scientific strand or by an integrated approach. For example, a common approach at the post-primary level is to divide Science into three strands of Biology, Chemistry and Physics, although this is not universal and there are various other categorisations used.

Figure 7 Excerpt from the International comparison: Science discipline/strand approach

Country	L1 (represents year in school, see age/year international comparison doc for ref)	L2	L3	L4	L5	L6	L7	L8	L9
Afghanistan (AFG)				*Natural Sciences: Men and environment* 2018 changed to: *Applied Science and Technology*	*Natural Sciences: Men and environment* 2018 changed to: *Applied Science and Technology*	*Natural Sciences: Men and environment* 2018 changed to: *Applied Science and Technology*	*Physics, Chemistry, Biology* 2018 changed to a *Applied Science and Technology* with the P,C & B division moved to Upper Secondary.	*Physics, Chemistry, Biology* 2018 changed to a *Applied Science and Technology* with the P,C & B division moved to Upper Secondary.	*Physics, Chemistry, Biology* 2018 changed to a *Applied Science and Technology* with the P,C & B division moved to Upper Secondary.
Bangladesh (BNG)	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*
Burundi (BUR)			*Sciences*	*Sciences*	*Sciences*	*Sciences*	*Physics, Chemistry, Biology, Earth Science*	*Physics, Chemistry, Biology, Earth Science*	*Physics, Chemistry, Biology, Earth Science*
Chad	**Not found.**								
Chile (CL)	*Integrated Natural Sciences*	*Integrated Natural Sciences*	*Integrated Natural Sciences*	*Integrated Natural Sciences*	*Integrated Natural Sciences*	*Integrated Natural Sciences*	*Integrated Natural Sciences*	*Physics, Chemistry and Biology.*	*Physics, Chemistry and Biology.*
Colombia (COL)		*Scientific Investigation and Natural Sciences*	*Scientific Investigation and Natural Sciences*	*Scientific Investigation and Natural Sciences*	*Scientific Investigation and Natural Sciences*	*Data unavail.*	*Data unavail.*	*Data unavail.*	*Data unavail.*
Cote D'Ivoire (COD)			*Life/Earth Science*	*Life/Earth Science*	*Life/Earth Science*	*Life/Earth Science*	*Streams: Experimental Science (Biology and Chemical Physics) and Exact Science (Mathematical Chemistry, quantitative experiments and data analysis)*	*Streams: Experimental Science (Biology and Chemical Physics) and Exact Science (Mathematical Chemistry, quantitative experiments and data analysis)*	*Streams: Experimental Science (Biology and Chemical Physics) and Exact Science (Mathematical Chemistry, quantitative experiments and data analysis)*
DRC (DRC)	*Environment and Sciences*	*Environment and Sciences*	*Environment and Sciences*	*Environment and Sciences*	*Environment and Sciences*	*Environment and Sciences*	*Environment and Sciences*	*General Studies*	*General Studies*
Germany (GER)	*Integrated Science*	*Integrated Science*	*Integrated Science*	*Integrated Science*	*Physics, Chemistry, Biology, Earth Science/Geography (academic stream) OR General Science (applied stream)*	*Physics, Chemistry, Biology, Earth Science/Geography (academic stream) OR General Science (applied stream)*	*Physics, Chemistry, Biology, Earth Science/Geography (academic stream) OR General Science (applied stream)*	*Physics, Chemistry, Biology, Earth Science/Geography (academic stream) OR General Science (applied stream)*	*Physics, Chemistry, Biology, Earth Science/Geography (academic stream) OR General Science (applied stream)*
India (IND)	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*	*Science*	*Physics, Chemistry, Biology*
Iran (IRN)	*Science and Health*	*Science and Health*	*Science and Health*	*Science and Health*	*Science and Health*	*Science*	*Science*	*Science*	*Physics, Chemistry, Biology, Laboratory (separate class, which integrates Chem & Bio), Environmental Sciences*

A mapping of the disciplinary approach provided the development team with a first level of structure to the mapping process. For example, if it was best to approach the mapping from a generalist perspective, or by discipline. Furthermore, if by discipline, what should those disciplines be? It was found that although many jurisdictions approach Science as a generalist subject in early years, the curriculum is often divided into units by discipline (Biology, Chemistry, etc.). In the later years, most jurisdictions have separate classes for different scientific disciplines. Most jurisdictions included the strands of Biology, Chemistry and Physics, however some offered additional strands. For example, in some jurisdictions, there were also classes in Earth Sciences, Geology and Astronomy.

After the strand mapping was complete, the research team then began mapping the specific curriculum content included in the curriculum documents collected. This was done using a matrix format (Table 12). Learning level was placed on the x-axis. Level one was equated to approximately four years of age and curricula were aligned using the age/level comparison document (Figure 6). On the y-axis, thematic areas of science were listed. The initial thematic areas were taken from the Ontario Science curriculum documents (Ontario Ministry of Education, 2007) which was recommended by a Cambridge International Science specialist based on the curriculum's clear and concise breakdown of common Science themes. When topics emerged from one of the jurisdictions being mapped that were not included in the initial y-axis topics, an additional row in the matrix was added to ensure that all elements of the curriculum being considered were being recognised in the mapping output.

Table 12: Curriculum mapping template

Strand	Content areas	L1	L2	L3	L4	L5	L6	L7	L8	L9
Physics themes	Structures									
	Mechanisms									
	Movement									
	Forces									
	Energy and Fuel (cross over with Chem)									
	Electricity, Currents, Magnetism and Electromagnetism									
	Systems									
	Flight									
	Waves: Optics, Sound and Energy Waves									
	General:									
Chemistry themes	Matter (atoms, molecules, elements, Compounds, Mixtures, Solutions									
	Properties of Liquids, Solids and Gases									
	Changes in Matter									
	Reactions and Energy									
	General:									
Earth and Space Science themes	Weather/Climate									
	Environment (local or earth)									
	Space/Cosmology									
	Water systems/Oceanography									
	Geology									
	Resources									
	Agriculture									
Health Science themes	Food/Nutrition									
	Hygiene & Lifestyle									
Technology Studies themes	General Technology									

When the mapping documents were complete for both the HPJs and the JHDs, the mapping documents were compared for commonalities and differences. Concepts which appeared across several curricula were noted as well as dominant organisational approaches. Outliers were also noted. It was important to take note of commonalities in order to potentially incorporate these elements into the curriculum framework and to support potential reintegration of learners (Development Principle 2, Table 2). In addition, it is important to make a note of outliers as well as examples of indigenous knowledge integration so that framework developers can be conscious of which areas may require flexibility when being locally adapted to local contexts. This also satisfies the fourth recommendation from the Research and Recommendations report (Cambridge University Press & Cambridge Assessment, 2020) which states that the framework should enable space for indigenous knowledge integration.

In addition to an analysis of various international curricula, several curriculum frameworks were also considered. These curriculum frameworks were internationally recognised and were often referenced in the academic literature that was consulted. These frameworks were considered for content, including depth and breadth, as well as their visual presentation. The curriculum frameworks that were considered were Big Ideas of Science (Harlen, 2010), Next Generation Science (NGSS, 2017), BEST Science (University of York Science Education Group, 2018) and the 2061 Benchmarks (AAAS, 1993). Overarching summaries of each of these frameworks were created and shared with the development team which provided guidance on possible conceptual and structural approaches that could be taken in the development of the Learning Passport Science framework. It must be recognised that all of these frameworks were written in English and originated from the United States or the United Kingdom. Efforts were taken to consider frameworks from non-English medium contexts, but none could be located publicly.

By reviewing these mapping outputs, framework summaries and relevant research, the Science development team developed an informed opinion of what core knowledge should be included in the framework and what knowledge should be left out. It was agreed by the development team that efforts must be taken to ensure that regional and local education specialists can integrate additional areas of knowledge to fit their needs when a specific curriculum is created based on the framework. Therefore, the knowledge contained within the framework only represents the minimum knowledge that should be included for children around the world.

5.1.2 Specialist consultation: expansion of the development team

In order to assist with the final decisions of what should be included in the framework, a group of specialists were recruited to collaborate with the Cambridge Assessment development team. Efforts were made to ensure that all scientific disciplines were represented and that both primary and secondary experts were included. All experts also had international experience and had been involved in a range of national and international science education projects. In total, eight specialists were recruited to be part of the Science Curriculum Framework development team:

1. Ann Fullick
2. Helen Harden
3. Ronald Mazorodze
4. Robin Millar (Lead consultant)
5. Marc Neesam
6. Judith Roberts
7. Tony Russell
8. David Shakespeare

This team of experts joined the development team and were involved throughout the Science framework development process. Please refer to Appendix 1 for their career biographies.

After the relevant research had been thoroughly considered and the detailed mapping exercises had been conducted and analysed, the development team in its entirety met for a two day workshop to explicitly define which areas of scientific knowledge should be included in this curriculum framework, how the framework should be organised and which method should be used to develop the framework descriptors.

The first goal of the workshop was to ensure that the newly expanded development team had a strong understanding of the project aims, parameters and theoretical underpinnings. Day 1 of the workshop focused primarily on introducing the guiding principles for the Learning Passport project and discussing key considerations in the field of Education in Emergencies (EiE). After this orientation, the development team discussed the curriculum mapping and research findings in order to decide the best way forward in the development process. It was decided that the first step would be to outline what scientific knowledge learners should know by the time they reach the age of 14. Following the development principles of Big Ideas of Science (2010), it was decided that these statements, referred to in this current project as Fundamental Ideas, would then become the end points that learners should reach. These statements will then serve as the organisational structure of the Science framework.

After this methodological approach was defined, developers began to distil the fundamental ideas of science. Workshop participants were reminded that these fundamental ideas must be based on disciplinary knowledge statements rather than simply listing concepts or practical skills. Various framework documents were available for the developers to consider such as the *Big Ideas of Science*, the *PISA Science Framework*, the *TIMSS Science Framework*, the *2061 Benchmarks*, the *Next Generation Science Standards*, *Best Evidence Science Teaching (BEST)* resources and others which they individually referred to. Developers first worked independently and then in groups based on science specialisms in order to develop a concise list of the fundamental ideas of science. It was recognised that this list of ideas would not include all ideas but would represent the key understandings that would allow learners to have a solid grounding in Science education and allow for further development in the future. Each group presented their list to the group. This was followed by a whole group discussion and collaborative refinement.

After the initial list of Fundamental Ideas was developed, the ideas were divided into the most appropriate scientific strands of Biology, Chemistry and Physics. These strands were selected based on the evidence emerging from the curriculum mapping document which showed that these represented the most common organisational approach to science knowledge across all jurisdictions considered. It was also acknowledged that several Fundamental Ideas may fall into more than one strand so intra-strand alignment would need to be ensured after the learning sequences were developed to ensure that the knowledge is developed in a logical and sequential way across the entire Science framework.

It was also recognised that there should be Fundamental Ideas about the practice of science in order to show the importance of integrating practical activities when the framework is developed into a curriculum. However, this list of Fundamental Ideas about Science would not be developed into learning sequences in order to allow for flexibility, applicability and appropriate resource availability when implemented into a specific local context. The Fundamental Ideas about Science were:

- Fundamental Idea 1: Living things are made of cells and the structure of cells, tissues, organs and systems are related to their functions
- Fundamental Idea 2: Chemical processes, including photosynthesis and respiration, occur in cells and are vital for life.
- Fundamental Idea 3: Living things interact with one another and the physical environment
- Fundamental Idea 4: Variation in organisms is due to inherited characteristics from their parent(s) and/or environmental factors
- Fundamental Idea 5: Materials are either made of a single substance (an element or compound) or a mixture of substances, where each substance has distinct properties.
- Fundamental Idea 6: All matter is made of substances which are composed of atoms.
- Fundamental Idea 7: The appearance, form and properties of substances can change, but mass is always conserved.
- Fundamental Idea 8: When a resultant force acts on an object, its velocity changes.
- Fundamental Idea 9: Energy is a property of a system (an object, or a group of interacting objects). When changes in a system occur energy is transferred within or between systems that interact, but the total amount of energy remains constant.
- Fundamental Idea 10: Light and sound radiate from sources interact with objects they reach, and are used to communicate information.
- Fundamental Idea 11: Forces between objects at a distance can be explained using the idea of a field.
- Fundamental Idea 12: The Earth is part of the solar system, which is a part of the Milky Way galaxy, which is one of billions of galaxies in the universe.
- Fundamental Idea 13: Chemical and physical processes affect the structure, composition and behaviour of systems in/on the Earth and its atmosphere.

In the next development activity, workshop participants were put into groups according to their area of specialism (Biology, Chemistry or Physics). Fundamental Ideas were then divided between these groups ensuring that specialists were working with the ideas that their knowledge and expertise relates most to. They were then tasked to create a short list of essential knowledge statements (referred to as *Essential Components*) that each Fundamental Idea should include. The purpose of this was to provide some parameters for the development of the learning sequences and to provide clarity on what was meant by each Fundamental Idea. For example:

Fundamental statement:
All matter is made of substances that are composed of atoms.
Essential components within this fundamental statement:

- Within the particle model there are interactions between the particles
- Particles can represent atoms or molecules
- Particles collide with the walls of the container and this accounts for pressure

This was done for all Fundamental Ideas. These Essential Components were then presented to the whole group for further refinement and alignment. It became clear that for some Fundamental Ideas, there were cross-cutting Essential Components. It was decided that these would be highlighted across the various learning sequences and revisited during Phase III of the development to ensure alignment.

After some further refinement took place, specialist groups then took their refined Essential Component lists and attempted to code each point as being developmentally appropriate for Lower Primary (labelled LP), Upper Primary (UP) or Lower Secondary (LS). Although the Learning Passport will not be designed based on grades or specific ages, it was worthwhile to reflect on the appropriate age at which these knowledge statements are introduced as this may assist when structuring the differing starting points for knowledge statements within the framework learning sequence. In addition, this helped to identify which Fundamental Ideas will be introduced later in the curriculum framework and which would start earlier. At the conclusion of the two-day workshop, the Fundamental Ideas were then divided amongst the development team (approximately two to three per team member) based on their science specialisms. Each development team member was then tasked with developing a learning sequence with L1-9 descriptors (when appropriate) for these Fundamental Ideas. This phase of the development will be further discussed in Stage S2 (5.2).

There were several development challenges faced throughout this workshop. This included time constraints and the challenge of developing a list of core knowledge statements within a contextually-agnostic paradigm. Due to limited resources available for external consultation as well as limited availability of the consultants, the workshop was limited to two days. Further refinement of the Fundamental Ideas, the Essential Components and the Ideas about Science would have been possible if additional days were available for group collaboration during this phase of development.

It was understandably very challenging for participants to distil the discipline of Science into a limited number of concise knowledge statements. Participants were hesitant to value one area or aspect more than another. As a result, several consultants reflected that further 'slimming down', especially of the listed Essential Components, will need to take place. A lean, but high quality, framework is necessary in order to allow for variability of teaching resources and variability in teaching time in the various local contexts in which this framework may be applied.

Due to the desire for this framework to be adaptable for various global contexts, the development at this phase attempted to be as contextually-agnostic as possible. However, it was challenging to objectively judge statements as contextually-agnostic without fully understanding the various contexts in which this framework could potentially be applied. In this way, it was a challenge to separate between variables and constants without a clearer sense of how, where, why and by whom this framework will be implemented.

5.2 Stage S2: Generating the subject framework descriptors

After the conclusion of the workshop, the members of the development team were given approximately eight weeks to create learning sequences for the Fundamental Ideas that they were each responsible for. In order to assist the specialists with this work, and in order to ensure there was consistency in development and in presentation, a template was provided for the development of each learning sequence.

The template was developed by two curriculum specialists within Cambridge Assessment. The template was structured so that each Fundamental Idea would be subdivided into the key sub-themes relevant to that Idea. To create these sub-themes, developers would need to answer the question, "What knowledge would learners need to know in order to build up their understanding to reach the understanding of the Fundamental Idea?" This use of sub-themes was mainly used to ensure that the framework developers thought critically about what threshold knowledge is required for each Fundamental Idea. Each of the sub-themes was then expressed as a sequence with descriptors ranging from Level 1 to 9. Since some sub-themes may be at a higher level than others, it was explained that some subthemes may not have a descriptor for each level. However, when the learnings sequences are seen as a whole, all levels contain descriptors.

Unlike Maths, full knowledge statements were required for each descriptor in the Science learning sequences as opposed to only a concept. This was done in order to avoid potential misinterpretation of the level or depth of knowledge required of the learner in order to progress in their learning. This also links to Development Principle 6 (Cannot rely on specialist teacher knowledge or guidance). The development team recognised that a knowledge statement does not necessarily solve this challenge, however it was believed that it would provide more support for accurate implementation than a singular term.

After the learning sequences were created, each member of the development team circulated the learning sequence they had created with the wider development team. Team members were asked to read through all sequences and to annotate the matrices with their questions, suggestions and general feedback. This allowed for a primary review process to take place. In addition, it allowed the development team to gather insight into how the learning sequences of the different Fundamental Ideas interrelate and what areas of alignment would need to be considered. Team members were given three weeks to complete this review process.

At the end of the three weeks, the development team met for an additional development workshop in order to refine and align the learning sequences which would make up the Science curriculum framework. In the first instance, teams were created which consisted of disciplinary specialists, similar to the teams created to develop the Essential Components during Workshop 1. Fundamental Ideas were then divided based on which disciplinary team was best suited to lead its revision. It was also ensured that the writer of the learning sequence was on the team that was responsible for its revision. This was done so the writer could explain their decision making and development process. Each team was given approximately four to five Fundamental Ideas to revise. By the end of this workshop day, most Fundamental Ideas had been revised. However due to the complexities of many of the Physics progressions, the Physics team required an additional workshop day to complete their revisions.

When all learning sequences had been revised, the development team met to discuss the interlinking concepts in order to ensure that learners acquire the required knowledge and the appropriate time in order to progress their learning across all areas of the Science framework. Based on this conversation, three specialists (representing Biology, Chemistry and Physics) were tasked with completing another revision of their respective Fundamental Ideas and to highlight areas they believe need further alignment with other Fundamental Ideas of the framework. This list was then used to establish intra-subject coherence which will be discussed further in Stage S3 (5.3).

By the conclusion of these workshops, a draft curriculum framework was created. However, efforts were still required to ensure coherence was achieved across the different learning sequences and that the framework was of a good standard when reviewed by specialist beyond the development team.

5.3 Stage S3: Establishing intra-subject coherence

Based on the reflections of the development team during Stage 2, a list of cross-cutting concepts had been identified. These concepts needed further attention to ensure that there was coherence across the learning sequences for each of the 13 Fundamental Ideas which comprise the LP Science framework. For example, the discussion of energy, measurement, cell theory, microorganisms and waves were mentioned as areas that required further reflection in order to ensure that the terms are used consistently. It was also important to check that any interrelated concepts which are required to understand more than one Fundamental Idea are introduced in only one learning sequence, in order to avoid repetition, and that they are introduced at the appropriate level in order to support learner progression across all related Fundamental Ideas. A detailed list of these concepts and knowledge elements was created jointly by the development team. The three specialist leads (Biology, Chemistry and Physics) then completed an additional revision in order to further ensure coherence across the Science framework.

In addition to ensuring that the learning sequences were coherent, the development team also identified a list of key vocabulary that should be defined to go alongside the Science framework. This document would help to ensure that curriculum developers working with the curriculum framework could accurately interpret the meaning that was intended by the development team. Due to the brevity of the learning descriptors, there is potential that these terms may be misinterpreted, especially if translated into other languages. For example, the term *wave* can refer to several phenomena, and ensuring the practitioner understands and uses the correct meaning is important for ensuring quality learning. Although this task is beyond the scope of this initial development phase, we recommend that this terminology list is developed during further piloting and contextualisation phases. Developing this list for a specific context will also ensure the linguistic and contextual appropriateness of the definitions and references. This also satisfies the second recommendation from the Research and Recommendation report for Science education which was: "terminology should be carefully chosen and key definitions should be provided" (Cambridge University Press & Cambridge Assessment, 2020).

After the alignment and coherence process was complete, an internal and external review process was initiated. The first step in this review process involved a specialist within the development team reviewing the entirety of the framework. This specialist was selected because of his strong knowledge and expertise across Biology, Chemistry and Physics. He also had experience reviewing international curriculum documentation. This reviewer spent two weeks inspecting the framework to identify areas requiring clarification and further alignment, and areas that were potentially over weighted or forgotten. His feedback was then sent to the development team's three specialists leads (Biology, Chemistry and Physics). These individuals looked through the internal feedback and amended the learning sequences where they felt it was necessary. Throughout this process, members of the development team were required to submit references which supported their position and decision-making process.

After this internal review process was complete, the framework was sent to Professor Jonathan Osborne for external review. Professor Osborne is a world leader in Science education and has been involved in a variety of curriculum development projects such as Next Generation Science and the UNESCO learning framework for Science (see Appendix 1). Professor Osborne was asked to review the curriculum framework and to provide feedback on all of the learning sequences included in the framework. He was also asked to respond to the following four questions:

1. Do the learning sequences make sense? What should be improved or added?
2. Do you think all key knowledge points are covered relating to the project aim?
3. Do you believe the presentation of the framework is clear and useable?
4. Are there any other comments you would like to raise?

In order to effectively answer these questions, it was imperative that Professor Osborne had a strong understanding of the project aims and parameters. In order to ensure he had this, a detailed orientation report was provided for Professor Osborne and a follow-up discussion was held so he could ask any further questions. This follow-up conversation also allowed the development team to ensure that Professor Osborne had a strong conceptual understanding of the Learning Passport project.

After this orientation, Professor Osborne spent one week reviewing the complete Science framework. He provided detail feedback on specific descriptors of each of the 13 Fundamental Idea sequences which showed the great care and attention he gave to the task. He also responded to the four overarching feedback questions with excellent constructive advice. After this feedback was submitted, an additional meeting was held with Professor Osborne in order to go through the key messages from his feedback. This also gave the development team time to ask questions about specific elements of the feedback that may not have been clear. The development team then amended the framework based on Professor's Osborne's feedback which involved merging several learning sequences together, adjusting the wording of several descriptors, and shifting the level of some descriptors. Overall, Professor Osborne believed the framework was well constructed considered the challenging task of attempting to remain context-agnostic and knowledge focused.

There are several areas of further development that were identified by Professor Osborne, which the development team also agree are worthy of exploration in the next phase of development. These areas include:

1. A related skills and/or competencies framework would be beneficial to support effective pedagogy and ensure authentic applicability of the knowledge statements included in the LP framework.
2. It is important to integrate epistemic knowledge when the framework is developed into an LP-based curriculum. For example, it is important for learners to understand what evidence has been gathered to develop current scientific knowledge and the potential evolution of scientific theories and models.
3. In order to ensure the applicability of this framework in practice, it is essential that a pilot LP-based curriculum is created. It would be ideal to have the LP framework development team involved in this curriculum development to ensure accurate interpretation of the framework, and to ensure that the framework can be further updated after the pilot.

At the conclusion of the review phase and after appropriate revisions had been completed to support intra-subject coherence within the Science framework, the development team began work to support inter-subject coherence across the different subject areas within the LP framework. This will be further discussed in section 7 of this report.

6 Science framework

6.1 Science framework overview

Fundamental Idea	Theme	Lower primary phase			Upper primary phase			Lower secondary phase		
		L1	L2	L3	L4	L5	L6	L7	L8	L9
1	**Living things and cells**									
2	**Vital chemical processes**									
3	**Micro-organisms**									
4	**Inheritance**									
5	**Material properties**									
6	**Matter**									
7	**Physical and chemical changes**									
8	**Force**									
9	**Energy**									
10	**Light and sound**									
11	**Fields and forces**									
12	**Earth in the universe**									
13	**Earth and its atmosphere**									

6.2 Detailed Science framework

6.2.1 Fundamental Idea 1: Living things are made of cells and the structure of cells, tissues, organs and systems are related to their functions

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
1.Living things and life processes	All things on the planet are living, non-living or once living	Living things can be sorted into two main groups – the animals and the plants			Important life processes include feeding, respiration and getting rid of waste.	All types of organisms must reproduce to replace themselves	The processes of life - movement, respiration, sensitivity, growth, reproduction, excretion and the need for food are used to decide if something is living or non-living.		
2.Structures/ functions in animals	Many common animals, including humans, have the same basic body structures, including senses.	The basic needs of animals, including humans, for survival are water, food and air	The human digestive system is made up of several parts with different functions, and care of the teeth is important to keep the system working well.	Humans and some other animals have bony skeletons which are adapted for support, protection and movement. The bones work with the muscles to move the body.	The basic parts of the human cardiovascular and respiratory systems, each have a specific function (limited to heart, blood vessels, blood, lungs, airways and respiratory muscles).	All mammals have the same basic reproductive organs		The respiratory system and the digestive system have adaptations which make them very efficient in their functions of exchanging gases and providing soluble food to all the cells	The specialised structures of the reproductive system in mammals are closely related to their functions.

					Non-communicable diseases that affect the heart and lungs are often linked to lifestyle factors e.g. smoking				
3.Structures in plants	Many common plants have the same basic body structures.	The basic needs of plants for survival are air, light, water and nutrients from the soil	The structure of roots, stems and leaves are linked to their functions in a plant.			Flowers are the reproductive systems in some plants and they produce fruits and seeds	Plants have transport systems that carry water and minerals from the roots in the soil to the rest of the plant.		Flowers can be pollinated by the wind or by insects and other animals, and this is very important for food security.
4.Cell structure and specialisms							Cells are the basic units of life, and all cells have some characteristics in common (including similarities and differences of plant and animal cells). Many cells in plants and animals are specialised for their functions.	Cells are organised into tissues and tissues into organs which work together as organ systems, and the structure of these systems is related to their functions.	

6.2.2 Fundamental Idea 2: Chemical processes, including photosynthesis and respiration, occur in cells and are vital for life.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Processes in plant and animal cells		All the processes of life (e.g. growth, movement) need fuel.	Food provides living things with vital chemicals and fuel.						Respiration is the process within all organisms by which the energy of food is made available to the cells, enabling other processes to occur. In most organisms, respiration depends on a supply of oxygen (aerobic respiration).
2.Animal nutrition	An animal's diet is made up of all the things it eats, which can be only plants, only animals or both.	The many nutrients and the fuel animals need for all their life processes and to stay healthy, come from what they eat.	A balanced diet provides all the essential nutrients and fuel an animal needs.						
3.Deficiency and			Unbalanced diets do not provide animals with	Lack of particular nutrients leads to illnesses					

oversupply diseases			all the nutrients and fuel they need, so their bodies do not function properly.	known as deficiency diseases. In many cases deficiency diseases can be cured by adding the missing nutrients to the diet.					
4.Plant nutrition		Plants require light, water, nutrients and warmth to grow.						Plant leaves and some stems contain chlorophyll which can absorb light. Gases move into and out of leaves through stomata. Plants use light to combine water and the gas carbon dioxide to make food materials such as sugars and starch which the plant uses to keep itself alive and this process is called photosynthesi s.	

5.Cellular biochemistry							Cells and tissues are composed of a great variety of complex materials, most of which cannot be used by the consumer without them being changed. Enzymes in the digestive system break food down into smaller units which can be absorbed into the bloodstream for transport to all cells		Enzymes in cells help many chemical reactions, including the fundamental processes of photosynthesis and respiration.

6.2.3 Fundamental Idea 3: Living things interact with one another and the physical environment[12]

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Abiotic and biotic factors in an environment	Physical (non-living) factors, including water, air, rocks and soil, create the great variety of environments found in different places on the earth	Each environment has physical characteristics which make it more or less difficult for living things to live in it	The balance of the various physical factors creates many smaller habitats within larger environments	Living things add to and take from any environment they inhabit					
2.Food chains, food webs and competition	Living things depend on physical factors to stay alive		Plants make food, and this feeds other living things directly or indirectly, as some animals eat plants and some eat other animals.	Diagrams can show the simple feeding relationships between plants and animals in a food chain	Several types of animals may all feed on the same plants or animals within a food web, so they compete for resources.		The physical environment provides factors vital to life, such as water, air, light and minerals, and organisms compete for them		
3.Adaptation to environment							Organisms are adapted to their physical environment and this helps them survive and reproduce	Individuals and populations which adapt best to changes in their environment	Each environment is populated by different organisms which are adapted to it, and their

[12] *Through Fundamental Ideas 3 and 4 the concept of Evolution can be integrated when the framework is developed into a full curriculum.

								have more chance of survival.	interactions can produce a stable /balanced ecosystem
4.Impact of change							Lack of food caused by changes in the physical environment can reduce populations	When environments change, particular types of living things may die out because the environment no longer provides them with all they need for survival	Changes in the physical environment caused by human behaviour can affect the populations of living things.
5.Diversity of micro-organisms		Tiny living things are found in water, soil, air and on the surfaces of living and non-living things.		Bacteria are very common, tiny living things which live in almost all environments.			Protozoa and some fungi are unicellular organisms - their whole body is just one cell. From birth we build up a population of beneficial micro-organisms in our gut (the gut flora) which are mostly bacteria	Most gut flora live in the large intestine and the faeces we make are mostly bacteria. The gut flora break down fibre and other materials, produce some vitamins and help the gut to absorb some minerals	The gut flora helps to defend the body by supporting the immune system and limiting growth of pathogens
6.Micro-organisms		Germs enter our bodies	Most germs die when they	To prevent food spoilage,	Pathogens are tiny living	Direct transmission	Indirect transmission		Antibiotics, antiseptics

include pathogens which can cause disease		when we breathe, eat and drink and also when we wound our skin. There are many ways we can reduce the number of germs we take in (e.g. washing hands and drinking clean water.	enter our bodies, killed by the defence systems of our bodies. There are infectious diseases that spread from one person to another through germs.	good hygiene in food preparation and storage is essential.	things that can make us ill or even kill us if we cannot successfully fight them off. Communicable diseases are caused by pathogens that are transmitted from one animal or plant to another.	is when there is contact that allows a pathogen to move from an infected to a healthy person, often through touch. Good hygiene reduces transmission of many pathogens.	occurs when a pathogen is carried from one person to another. By understanding routes of pathogen transmission, it is possible to interrupt them (e.g. mosquito nets).		and disinfectants are used to control micro-organisms. The immune system defends us against pathogens and the diseases they cause, and vaccines help the immune system do this faster and more effectively.

6.2.4 Fundamental Idea 4: Variation in organisms is due to inherited characteristics from their parent(s) and/or environmental factors[13]

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Life cycles	Seeds grow into mature plants if they have the right conditions.		The lifecycles of birds and reptiles usually involve egg-laying, although care of the eggs and of the young varies a lot.	The lifecycle of flowering plants includes flowers, seeds, fruit formation, dispersal of fruits and seeds, and growth of new plants	The lifecycles of insects and amphibians include a series of changes during development known as metamorphosis.	The lifecycle of mammals includes fertilisation of the egg cell, birth, growth and development, adulthood, reproduction, ageing and death.	Some insects act as vectors of disease in animals, including humans, and the stages of the lifecycles of the pathogens may take place in several different hosts or in water	Some insects act as pests of crop plants, and the lifecycles of the insects and the pathogens are coordinated with those of their host plants	
2.Variation in sexual and asexual reproduction		Plants and animals, including people, have offspring that grow into adults of the same kind			In asexual reproduction there is only one parent and the offspring are very similar to that parent.	In sexual reproduction offspring are of the same kind as their parents, but they normally show variation and are not identical to their parents.	Information is passed from one generation to another through the genetic information (DNA) that is passed on.	The variation between offspring produced by asexual reproduction is almost all the result of differences in their environment.	The variation between parents and offspring produced by sexual reproduction is the result of both genetic differences and environmental differences.
3.Mutations							Sometimes when genetic information is passed from		If mutations have an adverse effect on the

[13] *Through Fundamental Ideas 3 and 4 the concept of Evolution can be integrated when the framework is developed into a full curriculum.

							one generation to another, it can change randomly which is called mutation. This can lead to advantages and disadvantages.		structure or function of the cells or enzymes of the offspring, they may cause inherited diseases which can be passed from one generation to another e.g. preventing blood cells from carrying oxygen effectively.

6.2.5 Fundamental Idea 5: Materials are either made of a single substance (an element or compound) or a mixture of substances, where each substance has distinct properties.

Sub-theme	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Substances and properties	Objects, including living things, are found in the physical world and some objects are made for a purpose by humans	Objects are made up of different materials which have their own distinctive properties	Materials are chosen to make objects based on the properties of the material and the purpose of the object.	Materials can be made of a single substance or a mixture of substances	Properties of substances include; boiling point, melting point, and electrical and thermal conductivity.	Properties of substances also include solubility (soluble or insoluble).		A single substance is made up of one element or one compound. Every element and every compound has unique properties including density (the amount of mass in a given volume).	The Periodic Table shows patterns in the physical properties of elements.
2.Mixtures		Properties of materials include; hardness, colour, strength, etc.		A mixture is formed when two or more substances are added together, but do not join.	Some mixtures of two or more substances, including a solid (insoluble) and a liquid, can be separated using methods based on the physical properties of the substances.	Some mixtures of two or more substances, including a solid (soluble) which dissolves in a liquid, can be separated using methods based on the physical properties of the substances.			

6.2.6 Fundamental Idea 6: All matter is made of substances which are composed of atoms.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Atoms				Particles are used to represent what substances are made of.			Substances are made of atoms. And some of the evidence and arguments for believing this to be true.	Elements are substances made of only one type of atom and compounds are substances made of two or more types of atoms that are joined together	
							One model of the atom includes a central nucleus, made of protons and neutrons, surrounded by electrons. There is evidence to support this.	Different elements have different number of protons, neutrons and electrons.	The underlying organisation of the Periodic Table is based on the atomic structure of the elements.
							In this atomic model a proton has positive charge, a neutron has no charge and an electron has negative charge.	An atom is uncharged overall because it has an equal number of positive protons and negative electrons.	

2.Changes of state			Materials can be changed by physical action (e.g. stretching) or by heating or cooling.	Substances can exist in the solid (including powders), liquid of gas state. The particle model can be used to explain the physical characteristics of substances in the solid (including powders), liquid or gas state including that all particles are in constant random motion.	Substances change between the solid, liquid and gas states when they are heated or cooled and during these physical changes they remain the same substance. The particle model can be used to explain the process of change of state.	The particle model can be used to explain evaporation and diffusion in terms of individual particles from the liquid phase mixing with particles that make up the air. The particle model can be used to explain why a substance seems to disappear when it dissolves.			
5.Molecules								A molecule is made up of two or more atoms that are held together by electrostatic forces of attraction known as chemical bonds.	Atoms can form a range of structures.

6.2.7 Fundamental Idea 7: The appearance, form and properties of substances can change, but mass is always conserved.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Chemical reactions					Sometimes when a material is heated it is chemically changed (e.g. cooking or burning). After the change it is not the same substance.		During a chemical reaction a new substance, or substances, are formed. Chemical reactions can be observed due to a difference in properties between the products and reactants.	Chemical reactions involve rearranging atoms to form new substances. The total mass of the products is the same as the total mass of the reactants because no atoms have been created or destroyed in a chemical reaction.	There are three main types of chemical reaction; decomposition (breaking apart), oxidation (adding) and displacement (rearranging)
2.Chemical equations								Chemical reactions can be written as word equations.	Chemical reactions can be written as symbol equations.
3.Energy transfer					Burning a fuel increases the temperature of the surroundings.		Other evidence of a chemical reaction is a transfer of energy to and from surroundings		

6.2.8 Fundamental Idea 8: When a resultant force acts on an object, its velocity changes.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Forces			A push or a pull is called a force.	A force is needed to start an object moving, to slow a moving object, or to change the direction in which an object is moving. When an object experiences a push or a pull, we say that a force is exerted on (or acts on) it.		Forces cause changes in the shape of objects such as springs. The change in length of a spring can be used to measure the size of a force. The downward force on an object due to the gravitational attraction of the Earth is called its weight.	Forces arise from an interaction between two objects. Both objects experience a force of the same size, but acting in opposite directions on the other object. Most forces involve contact, but some (magnetic, electric, gravitational) act at a distance. A force always acts on a named object and is exerted by another named object. Friction (and drag) are forces opposing motion, exerted by the	A normal reaction is a force exerted by a solid surface on an object sitting (or pressing) on it. Tension is a force exerted by a string (or similar) on an object pulling on it. The moment of a force is its turning effect about a pivot measured by the product of the perpendicular distance of the force from the pivot. An object does not rotate about a pivot if the total clockwise and anti-clockwise moments are equal.	The resultant force on an object is the single force which would have the same effect as all the separate forces acting on it.

							surface an object is moving over, or the gas or liquid it is moving through.		
2.Pressure						Pressure is a measure of the force per unit area.	Liquids and gases exert pressure on surfaces. Pressure acts equally in all directions. Pressure is caused by the weight of the liquids and gases above, so it increases with depth.	Displacement of a liquid by an object in liquids causes an upthrust which is an upward force exerted on an object that is wholly or partially immersed in a liquid. Objects sink or float depending on whether the weight of the object is bigger or smaller than the upthrust.	
3.Motion	Distance travelled is measured in metres or kilometers	Displacement is the distance travelled in one direction. This is different from distance as it has a direction.				Speed is a measure of the distance an object travels in a given amount of time.	The average speed of an object is the distance it moves in a given time. The instantaneous speed of an object is its average speed		The velocity of an object is its speed in a given direction – that is its rate of change or displacement An object experiences a change of

							over a very short time interval. Instantaneous speed is what is measured by a speedometer.		velocity if its speed or its direction of motion changes e.g. The speed of the Moon in orbit is constant but its velocity is not. If the resultant force on an object is non-zero, its velocity changes. If the resultant force on an object is zero, its velocity does not change (i.e. it is either stationary, or moves at a constant speed in a straight line.) The change of velocity of an object is always in the same direction as the resultant force.

6.2.9 Fundamental Idea 9: Energy is a property of a system (an object, or a group of interacting objects). When changes in a system occur energy is transferred within or between systems that interact, but the total amount of energy remains constant.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Energy resources					To make something move, or to heat something, requires an energy resource. Fuels (wood, coal, oil, gas, etc.) are important primary energy resources; food[1] is the fuel for animals. Wind, sunlight, moving water (flowing rivers, tidal movements, waves) are also important primary energy resources. Electricity has to be		The amounts of energy needed and supplied by different fuels and foods, can be measured. The power rating of an electrical appliance indicates the amount of energy that has to be supplied to it every second.		Different ways of achieving the same outcome may require different amounts of energy. One process or device can be more efficient than another, if it needs less energy do the same job.

					generated from a primary energy resource.				
2.Thermal processes				Temperature is a measure of how hot or cold something is.			Energy transfers spontaneously from an object at a higher temperature to one at a lower temperature. The temperature of the object that loses energy falls, whilst that of the object that gains energy rises.	The transfer of energy by a temperature difference can occur by conduction, convection or radiation. An object stays at a steady temperature if energy is transferred to it at the same rate as it transfers energy to its surroundings. Objects are heated (by friction) when they rub together.	
3.Energy transfer, conservation and dissipation					Work is done (and energy is transferred) when a force moves an object. The bigger the force or distance, the			When two or more systems interact, the energy of one system gets less, whilst the energy of one or more other systems increases by	Any machine can transfer the same amount of energy by exerting a large force over a small distance or a small force

					more work is done.			the same amount. The total amount of energy remains the same (energy is conserved). An indicator that the energy of a system has changed is if it: moves faster/slower; gets hotter/cooler; changes chemically; is moved by/against an electric, magnetic or gravitational field; has been stretched/compressed. When energy is spread among a larger number of systems, it becomes less useful and harder to do other jobs. The energy is said to be dissipated.	over a large distance. Humans can only exert small forces over large distances and use pulleys, levers and ramps to lift objects which they are unable to lift directly.

4.Electric circuits				An electric current is a means of transferring energy over very long distances.	A working electric circuit requires a closed loop of conducting material from one terminal of a battery (or power supply) to the other terminal. A switch breaks or completes a closed loop. Some materials are electrical conductors, others are insulators.	In a series circuit, the current is the same at all points in the circuit. In a circuit with parallel branches, the current in each branch can be different.	An electric current is a means of transferring energy from one location to another – often over very long distances. This gives it a major advantage over other forms of energy such as oil and gas. In addition, it can be used for an enormous range of tasks easily from running a motor, lighting a lamp to heating a house.	The wires and components of an electric circuit contain electrons that are free to move. A battery (or power supply) causes the movement of these electrons together around the circuit. This movement is called an electric charge. The size of the electric current at a point is a measure of the amount of charge passing that point each second.	The size of the electric current in a circuit depends on the size of the potential difference (or voltage) of the battery (or power supply) and the resistance of the components to the movement of electrons around the circuit.

6.2.10 Fundamental Idea 10: Light and sound radiate from sources interact with objects they reach, and are used to communicate information.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Light			Luminous objects, such as lamps, flames, and the Sun, are sources of light. Light scatters from objects that it hits into our eyes, enabling us to see them. Darkness is the absence of light.	We see an object when light emitted by it or scattered from it enters our eye.	Light travels in straight lines in all directions from a source. Light passes through transparent objects and materials but is stopped by opaque ones. When an object stops some of the light from a source, a shadow is formed. The shadow is the region which light from the source cannot reach. Light can travel through a vacuum.	Normally light is scattered in all directions from any object it hits. With a plane mirror, the reflected beam is at the same angle to the mirror as the incident beam.	The intensity of light from a source diminishes the further it goes, because it is spread over an ever-increasing area, and because it may be gradually absorbed by the medium it is travelling through. When light strikes an object, it may go straight through (transmission), bounce off (scattering or reflection), or be stopped (absorption) – or a combination of these. When light is absorbed by an object, it usually just	A light beam changes direction when it crosses the boundary between two different transparent media at an inclined angle. This is called refraction. The reflection of light by a mirror produces an image of an object beyond the mirror. Visible light is one type of electromagnetic radiation that is a wave. Other types of electromagnetic radiation behave in similar ways to light, though type differs in the length of the	White light is a mixture of all the colours of the spectrum. A coloured filter transmits light of one (or more) colours and absorbs light of the other colours of the spectrum. The observed colour of an object is that of the light it scatters.

							makes it hotter, but it can also cause chemical or electrical effects.	wave and frequency of the radiation.	
2.Sound				Sounds are produced by vibrating objects. The larger the vibration, the louder the sound. The faster the vibration, the higher pitched the sound.	Sound travels from a source. Sounds can travel in directional or non-directional patterns. Sound requires a medium (gas, liquid or solid) to travel through.	Sound is reflected by hard surfaces. This can cause an echo.	Sounds get fainter as the distance from the source increases, because they are spread over an ever-increasing area, and are also gradually absorbed by the medium they travel through.		

6.2.11 Fundamental Idea 11: Forces between objects at a distance can be explained using the idea of a field.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Magnets and magnetism			A magnet attracts (pulls on) some materials (which we call magnetic materials). These include some metals, notably iron. A magnetic attraction can be felt across a gap, and through materials (such as paint, paper, and card).		A magnet attracts or repels another magnet, depending on which points on the magnets are brought close together. A magnet has two specific places (called poles) at which its magnetic effect is strongest. There are two types of magnetic pole, which we call north-seeking (N) and south-seeking (S). Like poles repel each other; unlike poles attract.		An object made of a magnetic material becomes a magnet while it is close to a permanent magnet. This causes an attractive force between them.	Around any magnet there is a region in which another magnet experiences a force. We call this region a magnetic field. The field at any point has a direction and it gets gradually weaker with distance from the magnet that is causing it.	
2.Electric charge					If certain materials are rubbed, they become electrically charged and		There are two types of electric charge, which we call positive and negative. Two	Around any electrically charged object there is a region in which another charged object	

					attract some light objects. A charged object discharges by gradually sharing its charge with its surroundings, including the air.		objects with the same type of charge repel; two with different types of charge attract. The forces between charged objects act across the space between them. Most objects contain equal amounts of positive and negative charge, and so are electrically neutral (uncharged). When an object is charged by rubbing, electrons (tiny objects with a permanent negative charge) are transferred to or from it.	experiences a force. We call this region an electric field. The field at any point has a direction, and it gets gradually weaker with distance from the charged object that is causing it.	
3.Gravitation					An unsupported object falls downwards because of the gravitational		There is a force of attraction (called gravitational force) between	All masses exert a gravitational pull on other masses. The masses are	

					force exerted on it by the Earth. This gravitational force is the weight of the object.		any two masses. It only becomes easy to detect when one of the objects is extremely large, such as the Earth. The gravitational force between two objects acts across the space between them.	said to have a gravitational field. The field is always attractive and has a direction which is directly between the two masses. The field gets weaker with the distance between the two masses.	

6.2.12 Fundamental Idea 12: The Earth is part of the solar system, which is a part of the Milky Way galaxy, which is one of billions of galaxies in the universe.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.Observations from Earth			The Earth, the Sun and the moon are roughly spherical. The Sun appears to move steadily across the sky every day, roughly from east to west. The Moon and stars appear to move steadily across the night sky, also from east to west. The Sun is a million times larger than the Earth which is 6 times larger than the Moon	The Earth rotates once a day about a north-south axis which causes day and night, and the apparent motion of the Sun, Moon and stars across the sky. We know this from the evidence of Foucault's Pendulum and photographs taken of the stars at night with the shutter left open. All the stars appear to rotate around the Pole Star. The simplest explanation is that the ground on which the camera is sitting is turning once	The Earth orbits the Sun in an almost circular path, taking one year for a complete orbit. The Earth's axis is tilted relative to the plane of its orbit so that the length of day varies with position on the Earth's surface and time of the year, giving rise to the seasons. The Sun (and the stars) are primary sources of light. The Moon is not a primary source of light; only those parts illuminated by	As seen from Earth, the stars all appear to move together across the sky, keeping the same pattern. Planets move relative to the background of stars.	The direction which we call 'down' is towards the centre of the Earth.		

				every 24 hours.	the Sun are seen. The Moon orbits the Earth taking about 28 days for a complete orbit. During this period, the appearance of the Moon changes in a regular pattern. During this time, the Moon also spins once on its axis so that it always keeps the same face towards us.				
2.Solar system and beyond						The Earth is one of eight (so far known) planets in the solar system which, along with other smaller bodies, orbit the Sun in roughly circular paths, at different distances from the Sun.	The gravitational force of attraction between objects keeps the planets (and the other smaller objects in the solar system) in their orbits round the Sun.	The Sun is one of a hundred, thousand million stars (separated by very large distances) that together make up a galaxy called the Milky Way. Our solar system is a small part of a galaxy (the	Distances in the universe are so large that it is convenient to measure them in light years (the distance that light travels in one year).

								Milky Way), one of many billions in the Universe.	

6.2.13 Fundamental Idea 13: Chemical and physical processes affect the structure, composition and behaviour of systems in/on the Earth and its atmosphere.

Sub-themes	Lower primary phase			Upper primary phase			Lower secondary phase		
	L1	L2	L3	L4	L5	L6	L7	L8	L9
1.The atmosphere and water					On Earth, water is found as a liquid (seas, rivers, lakes, underground aquifers, clouds), a solid (ice caps, glaciers, clouds) and as a gas (in the air) (see ST9). Most of Earth's water is saltwater, with only small and limited amounts of fresh water.	The Earth's atmosphere contains nitrogen (79%), oxygen (20%) and small amounts of other gases including carbon dioxide and water vapour.	A supply of fresh, clean water is vital for human life. Human activities can lead to shortages of potable water and water shortages in general which pose a threat to us and other living things in the short and longer term. Human activities and natural processes can lead to substances being added to or removed from the atmosphere. This has local and global effects.		
2.Cycles						Water on the Earth's surface and in		Carbon is cycled through the	

						the atmosphere is cycled through evaporation, condensation and precipitation.		atmosphere and environment during photosynthesis, respiration, burning and other processes. Nitrogen is cycled through the atmosphere and environment through chemical reactions, and the action of plants and other living things.	
3.Weather and climate			The weather changes day-by-day, and season-by-season.		Weather is determined by the conditions and movement of the air. Studying the conditions and movement of the air over time allows us to predict the weather a short time		Differences in pressure cause air to move, resulting in winds and changing weather patterns.	The Earth's temperature is dependent on the balance between electromagnetic radiation from the sun and the electromagnetic radiation Earth emits into space. Gases in the atmosphere reduce the rate	Human activities, such as burning fuels and farming, produce carbon dioxide and methane, increasing the greenhouse effect, leading to a rise in the Earth's temperature and causing

					ahead a week at a time. The climate (longer term weather patterns) is different in different parts of the world. Studying longer term weather patterns over periods of several years or more allows us to predict the climate over the years ahead.			of emission of electromagnetic radiation from Earth making the Earth's temperature higher than it would otherwise be. This is called 'the greenhouse effect'.	climate change.
4.Geology			There are many different kinds of rocks, which have their own, different appearances and properties. Most can be grouped into three basic categories.		Wind, liquid water and ice break rocks down gradually, some of which become parts of soils.		Inside the Earth is a core, mantle, and just below the surface is the crust. The main rock types in the crust (igneous, sedimentary, metamorphic) are formed in different ways over different timescales.		The Earth's crust consists of large plates which 'float' on the mantle, The convection currents in the mantle push them towards and apart from each other. Many volcanoes and earthquakes occur at the boundaries

									between these plates.

7 Inter-subject coherence

To deal with inter-subject coherence across Maths and Science we convened a workshop involving four subject experts who had previously been involved with the framework development (Paula Beverley, Rachael Horsman, Ellen Jameson, David Shakespeare). The participants' expertise ranged across both the Primary and Secondary education levels.

The overall aim for this part of the development was to identify a list of interlinking Maths and Science concepts to ensure that that the framework levels conveyed a logical learning sequence between both subjects.

To achieve this, the workshop had a number of specific aims:

- To outline the Maths and Science framework matrices to the experts so that they were familiar with how the subjects were represented and the content organised
- To encourage expert discussion and consensus building around a method that could link the content of the Maths and Science matrices
- To establish a coherence of cognitive and conceptual demand across the Maths and Science framework
- To create a reference document that could support coherence when the framework is developed into a contextualised curriculum

To facilitate productive discussion during the workshop, two tasks were completed in advance of the meeting. The first task involved a restructuring of the Maths framework to bring the structure into line with that of the Science framework. We needed the organisation of the descriptors in both subject areas to conform to a common structure that contained the same number of sequence levels. An initial meeting with the Maths experts highlighted that there were more descriptors in the Maths framework compared to the Science framework. Moreover, it was clear that some of these additional descriptors would apply to the very earliest stages of learning (and so would be antecedents for some of the Science content). Rachael Horsman carried out an additional review of the Maths framework to identify whether any descriptors could be further collapsed into each other (i.e. become more 'high-level'), and whether any of these descriptors would fall into what might be considered to be an Early Years (e.g. pre-Primary) education phase. As a result, three additional *EY* levels were added to the framework to precede the nine levels of the original framework structure. Table 13 shows a model of this new Maths framework.

Table 13: Subject Framework Structure

			Levels											
Domain	Main concept	Code	EY 1	EY 2	EY 3	1	2	3	4	5	6	7	8	9

The second task that preceded the coherence workshop involved a Science expert (who had been involved with the framework development) reviewing the science content to identify any potential overlap with Maths knowledge and concepts. David Shakespeare carried out this review as he had a broad overview of all the different areas of the Science framework. In this initial review he indicated whether any of the Fundamental Idea descriptors had a need for facilitating Maths knowledge (e.g. 'dealing with magnification' in Science would require an understanding of 'scale' in Maths; or dealing with 'chance of survival' in Science would require an understanding of 'likelihood').

The workshop involved a discursive method, with the experts coming to a shared understanding of the concepts in each framework. To do this, the Science expert who had carried out the pre-workshop review explained where he perceived there to be a need for facilitating Maths knowledge in any particular Fundamental Idea descriptor in the Science framework.

This elaborated outline allowed the Maths experts to locate the allied knowledge in the Maths framework. Moreover, the Maths experts identified the descriptor where this key knowledge was located (i.e. at which particular level of the Maths framework). To reach this common understanding the experts would often engage in discussion about how these concepts could potentially be taught.

The next stage of the workshop involved the experts checking that the sequence of descriptors were coherent. In other words, they were looking to ensure that any important Maths knowledge appeared in the framework prior to, or at least at a parallel level to, where it would be required in the Science framework. At this stage there was a potential to reorder the descriptors in the matrix if there were reverse relations of development.

During this process the experts agreed on the need for additional refinements to the two subject frameworks. At times they identified missing concepts in the detail of the Maths framework that needed to be added. These included the need to include some reference to Sorting, 'Big' numbers (e.g. 'billions') in Place Value, and the refinement of the Compound Measures descriptors beyond Level 6. The process also identified some areas of the Science framework that needed to be augmented. These included some refinement of the descriptor of Mass, and the need to add some reference to Enlargement around the concepts of Light and Lines. Finally, the exercise allowed us to identify some areas where the content of the Science framework would lead the development of Maths learning. For example, it was agreed that the introduction of Exponential Growth should be an element that would be introduced in Science before being covered in the Maths framework. This refinement was carried out by experts following the workshop.

An outcome of the workshop was the development of a document that links the Maths and Science framework matrices at the level of their cognitive and conceptual demand. This document (presented as a table Section 8) is crucially important for anyone who, in the future, needs to convert the framework into a broader, contextualised curriculum. Any organisation of learning based on this framework needs to take into consideration the conceptual links and ordering conveyed in Section 8 so that there is coherence across the learning levels.

8 Linking concepts across Maths and Science

Science			Maths
FI* Level	Code(s)	Linking concept	Domain Code(s)
1	2.8; 9	Volume, surface area, ratio	Con 7
	4.7	2D and 3D shape representation	P-S 6
	4.7	Scaling	Len 6
2	2; 3.3	Balance, weighting, and fractions	FPE 2
	5.7; 9	Tessellation and congruency	C&S 3
3	3.5	Number line structure; very large numbers	SE 1; PV 5
	3.8	Chance, probability	P&R 2
	4.7	Graphing data	TSB 4
4	2.6+	Probability links to random chance	P&R 2
	2.7	Describing 3D shapes	Shp 4; TmEY 3
	3.7	Probability links to random chance	P&R 2
5	1.5	Number comparison; number line; sorting	N 3; Len 4; UWDEY 3
	1.8	Compound measures	CF6
6	1.4+	Relative scales	SE 1
	1.7+	Change situations	AS 1
	2.5	Scales and negative numbers; equivalences	N 3; EQ 1
6	5.8; 9	Changing shapes; constructing 3D shapes	Con 3; Vol 3
7	1.8	Conservation (pacing off)	Wei 3
	2.8	Symbolic expressions, representations and functions	RF 5
	3.5	Number comparison; number line	N 3; Len 4
8	1.6	Units	Len 4
	1.8	Compound measures; pivoting, rotating, clockwise/anti-clockwise	CF 6; Ang 4
	3.7	Compound measure; equations	CF 6; EQ 5
9	1.7	Rates	CF 6
	2.4	Number comparison, number line, and scales	N 3
	3.9	Relationships, functions, and constraints	RF 2
10	1.5; 7; 8	Angles, rotations, turns, reflection, angle types, and inverse relationships	Ang 4; Shp 2; SIT 4
	2.4	Rates	RF 2; CF 6; PF 3
9	4.7	Units	Len 4
11	1; 2; 3.8	Proportion	RF 2

12	1.3	Identifying 2D and 3D shapes	ShpEY 1
	1.4+	Rotation/circular motion; recognising rotational symmetry; time; 3D; perspective	Ang 4; SITEY 3; TmEY 3; Con 3
	2.6+	Orbital rotation links to the circle	Shp 1
	2.8+	Extremely large numbers; compound measures; recognised units	PV 5
13	1.6	Percentages and fractions	PE 4
	3.5	Communicating trends in data; estimating time	TSB 4; Tm 4

*Fundamental Idea

9 Literacy framework development

The development of the Literacy Framework faced a number of challenges. The specification called for a framework which is independent of specific language structures and cultural norms. This is sensible at one level, since it is desirable to try to describe language structure as it corresponds to existing and possible cognitive and human development per se, rather than attend to the highly variable structural and surface features of specific languages. Without attempting this generalized abstraction, many frameworks would be needed, not one. But there has proved to be two challenges to this:

1. A sufficiently analytic framework has to attend to the nature of progression in language development and thus use surface and structural variation to describe the progression.
2. Cognition is not independent of language – for example the structure of causal statements and logical entailments unfold differently in different languages. Reading speed (fluency) varies with language structure, there is different phonemic correspondence between spoken and written forms in different language heritages, and so on.

These challenges introduced far more demand for the development process than would be required to develop a framework for a specific linguistic and cultural milieu. A breakthrough came with the team's consideration of the Progress in International Reading Literacy Study (PIRLS) framework[14], which has persisted as a well-evidenced and trans-language common description of language acquisition.

Additionally, we explored the L1-L+ relationship, recognising that many displaced children find themselves in an L+ context. Some literature on L+ acquisition suggests that L+ acquisition for young children (pre-7) in immersive contexts is not significantly dissimilar in pace and form to L1 acquisition (Abadzi, 2006, 2013; Cummins 1980). However, after this early period, L+ acquisition is more demanding, typically proceeds more slowly, and requires more structured and deliberate learning. Good L+ progression structures exist in the form of the European Europass Levels (European Union and Council of Europe; 2004-2013). We thus have focused on L1 acquisition, and used resources including PIRLS and the National Curriculum for England as benchmarks. We have used leading oracy research which suggests oral acquisition of words (and their related concepts) and complex language structures proceeds in advance of the use of the same in written language. We have in addition added a separate extra analysis of reading and writing speed and suggest, as part of the next stage of language specific implementation, the development of small succinct tables which are language-specific indicators (benchmarks).

The development of the Literacy framework differed from the development of the Maths and Science frameworks in the way that it was benchmarked according to learner age (rather than being organised around generic, age-agnostic levels). This difference reflects differences in the process of language acquisition in comparison to how learners' understandings of mathematical or scientific concepts develop.

The learning milestones in the Literacy framework are organised according to three dimensions: *Oracy*, *Reading*, and *Writing*. Oracy includes the skills of speaking and listening and the development and application of a set of skills associated with effective

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[14] McGrane, J., Stiff, J., Baird, J., Lenkeit, J., & Hopfenbeck, T. (2017).

spoken communication (Wilkinson, 1965). We chose to use oracy as one dimension of Literacy as it subsumes both speaking and listening, and the performance of most forms of talk necessarily involves listening. Reading is organised into *Knowledge/text awareness* and *Comprehension development*. Writing is organised into *Physical aspects of writing*, *Transcription*, and *Composition*. Physical aspects of writing include handwriting and other aspects of writing that entail motor control. In young children these include sitting correctly and having sufficient hand-eye coordination to handle a writing implement. Transcription is the process of representing speech sounds by means of symbols. In many languages, correct transcription requires knowledge of grammar, punctuation, and combining symbols correctly to form words and sentences. Composition is an intellectual creation. Composing entails planning, drafting, writing, reviewing and editing text. The judgements made during these processes require understanding of the text's purpose and audience.

The learning milestones in the framework cover learning expectations between the ages 0-14. Due to the interrelations between the phases of cognitive development and L1 literacy acquisition, it is recommended that learners are supported to reach the targeted level of literacy by the age benchmarked in the framework. This also differs from the Maths and Science frameworks which are focused more on progression through the sequence and not on specific age/level alignment.

The descriptors in each age range of the Literacy framework represent the learning that might be expected from a learner at the end of that year (i.e. '6 Years' includes literacy skill development that is possible for some learners by the time they reach the age of 7).

There are deliberate spaces in the framework at some age points. These spaces indicate that there is not a specific learning milestone for that specific dimension in that year. These spaces allow framework users to integrate time for additional reinforcement of previous milestones and to support the learner in progressing towards the succeeding milestone that they should master the following year. This space provides users with valuable flexibility to develop a more learner-centred curriculum that supports the needs and abilities of learners in their context. It should not be interpreted that there is no development taking place during a year that has no explicit descriptor. For example, curriculum or materials developers would be expected to encourage practice and reinforcement of previously acquired content in these spaces and to begin exploration of the next upcoming milestone. How this is specifically broken down between years should be done at the local level in a way that is relevant and logical to the context. This parsimonious arrangement of milestones is a feature of the Curriculum Framework.

Within many of the learning milestone descriptors there is text in blue highlight. This highlighted content needs particular consideration for possible modification/revision by those responsible for developing a curriculum and allied materials, in order to make them relevant to a given language. It is expected that these specialists will be best placed to check whether the highlighted concepts apply to the language context of the development.

10 Literacy framework

0-1 Years

Oracy
Communicates needs and feelings in a variety of ways (e.g., crying, gurgling, babbling and squealing). Makes own sounds when talked to. Conventional social gestures emerge. Uses simple sounds or words purposefully and attempts to name familiar objects. Creates personal words as they begin to develop language. Imitates one-, two- and three-syllable nonsense sounds/words **(e.g. 'doe-per-lut')** [15].   Discriminates between phonemes. Stops and looks when hears own name and looks at a person when they are speaking. Responds with understanding to some words used in their usual context. Moves whole body to sounds they enjoy, such as music or a regular beat.
Reading
Knowledge/text awareness: Handles books and understands that they can be opened and pages can be turned. Shows understanding that pages are different.
Writing
No specific age-level milestone.

[15] The text in **blue highlight** throughout the framework needs to be considered for possible modification/revision by those responsible for developing a language-specific curriculum and allied materials. It is expected that these specialists will be best placed to check whether the highlighted concepts apply to their language context.

2 Years

Oracy
Joins in with singing or actions and copies familiar expressions. Talks about familiar objects in simple terms **stringing together two or more words to form simple sentences** and asks simple questions. Uses different types of everyday words (nouns, verbs **and adjectives**). Begins to talk about people and things that are not present. Responds to simple questions and familiar one-step instructions. Selects familiar objects by name and will go and find objects when asked or will identify objects from a group.
Reading
Knowledge/text awareness: Begins to see writing symbols (**letters/characters, etc.**) as different from scrawl. Understands that writing can correlate to specific sounds. Can effectively hold a book and is able to turn pages in the correct order. **Comprehension development:** Focuses, interacts with, and responds to pictures (gestures, sounds, etc.). Begins to understand that some words connect with nearby pictures.
Writing
Physical aspects of writing: Experiments with making marks.

3 Years

Oracy
Begins to engage in word play and joins in with songs and rhymes. Talks using simple sentences of up to 4 or 5 words. Uses language to share feelings, experiences and thoughts, and to refer to something in the past. Uses a variety of questions. **Begins to use word endings.** Listens to and remembers simple stories with pictures. **Understands 'who', 'what', and 'where' in simple questions.** Understands more complex sentences **(e.g. 'Put your toys away and then we'll read a book').**
Reading
Knowledge/text awareness: Identifies writing symbols and can connect some symbols and their associated sounds or words. Compares the different sounds. **Comprehension development:** Retells some aspects of a story. Answers simple questions about stories related to characters and setting. Answers simple questions about their feelings related to stories that they hear.
Writing
Physical aspects of writing: Begins mark making with an implement.

4 Years

Oracy
Speaks clearly and uses intonation and rhythm. Retells an event or experience in the correct order **and in sentences with five or more words**. Begins to use more complex sentences to link thoughts **(e.g. using 'and', 'because')**. **Sentences may contain embedded clauses (e.g. 'don't touch that 'coz you'll break it and I haven't finished yet')**. Understands and uses colour, number and time related words. **Uses a range of tenses (e.g. play, playing, will play, played)**. Understands two-step instructions and asks simple appropriate questions. Follows directions. **Shows understanding of prepositions such as 'under', 'on top', and 'behind'**.
Reading
Knowledge/text awareness: Has a basic awareness of symbol-sound correspondence. Focuses on meaningful print and discusses similarities and differences between **symbols**. Identifies words as discrete and meaningful groups of **symbols**. Begins to recognise and connect words they see in their environment to their meaning (e.g. labels or signs). Links **words** that have similar written or sound characteristics. **Comprehension development:** Begins to predict meaning of **words** based on their placement (beside a picture or on a label of an object). Begins to predict outcomes in stories and has a basic understanding of cause and consequence. Compares events or experiences in stories to their own experiences. Understands that some texts are make-believe (fiction) and others are based on fact.
Writing
Physical aspects of writing: Makes marks with an implement that are recognisable as symbols. Makes marks in the same direction as those used in the L1. **Transcription:** Makes marks to show ideas and ascribes meanings to these. **Composition:** Dictates their ideas for writing. Develops strategies for writing independently.

5 Years

Oracy
Interacts with others in a variety of contexts and takes turns in conversation. Includes information that will influence the listener. Memorises and performs songs **and rhymes** (develops phonological short-term memory) **and shows recognition of rhythm, rhyme and spoken alliteration**. Distinguishes or segments words, syllables, or phonemes, **recognises words that rhyme or sound similar**, and identifies initial sounds. Uses well-formed sentences. Engages in two-channel attention, understanding three-step spoken instructions without stopping to look at the speaker. Understands modals and engages with conditionals. Shows inferencing skill (able to identify missing information based on background knowledge).
Reading
Knowledge/text awareness: Increases their awareness of **symbol-sound** correspondence and begins to acquire basic decoding strategies. **Connects a series of connected symbols with merged sounds**. Conducts oral blending of sounds to read several everyday frequent **words aloud clearly** with support and modelling. Is aware of directionality and purpose of print. Understands there is a particular sequence in writing (e.g. beginning, middle, end). **Comprehension development:** Understands that information can be gathered from non-fiction texts. Identifies the main events and actors in an age-appropriate story. Uses simple **phonics to decode simple, everyday words**. Decreases their reliance on picture prompts to gain understanding of text. Retells all important elements of a basic story. Connects or compares a story to other stories or their life.
Writing
Physical aspects of writing: Shows good control and co-ordination in large and small movement. Forms high frequency symbols that can be recognised. Handles writing implements for mark making. **Transcription:** Shows awareness of how writing works **(e.g. use of letters/characters, spacing and direction to convey meaning). Writes high frequency symbols and simple words linked to sounds and/or other meanings**. Writes words of personal importance (e.g. their name). Understands and uses simple **punctuation**. **Composition**: Writes a simple sentence, which may contain errors, but can be understood.

6 Years

Oracy
Asks questions to clarify understanding.
Reading
Knowledge/text awareness: Continues to develop their phonological awareness and effectively makes connections between the symbols used in their language and the related sounds. Reads familiar words at a level of automaticity. Is aware of the different physical structures and patterns of **words, sentences** and larger groupings in text which assists them in knowing when to pause. Uses several **decoding strategies** to sound out **words**. Understands that basic groupings of **words (e.g. sentences)** convey a complete idea and have related **syntax**. Is aware of text and book attributes (title, beginning, middle, end, author, **cover, spine**, etc.). May not be able to access print independently. However, over time, plays a more active role in reading. **Comprehension development:** Reads by relying principally on memory/recall, their growing understanding of known stories, and a willingness to interpret and invent based on what they have heard and can see. Responds to texts through questions and imaginative play.
Writing
Physical aspects of writing: Sits and holds a writing implement comfortably and correctly. Is aware of symbol and/or word spacing. Forms digits **0-9**. **Transcription:** Writes high frequency symbols. Writes down the sounds heard (symbols or combinations of symbols). Writes high frequency simple words, **including plural forms**. Recalls and writes simple sentences that are dictated out loud. Begins to **punctuate** sentences. Uses simple grammatical terminology to discuss their writing. **Composition:** Is aware that writing can be done for different simple purposes. Composes and writes a simple sentence. Sequences sentences to form narratives. Reflects on what they have written and discusses with others.

7 Years

Oracy
Expresses opinions, giving reasons, and speaking clearly to a range of audiences. Identifies beginning and end sounds in words. **Uses sound and letter links to read and spell unfamiliar words**. Is aware of peer language and the need to use different styles of talk with different people. Exaggerates in an implausible way, to make stories more exciting. Retells narratives or information that they have heard, sequencing events correctly. Listens to other speakers, responds to key points and relates understanding to own experience.
Reading
Knowledge/text awareness: Draws on their developing **phonological** knowledge by linking **more complex symbol groupings to specific sounds** to help them read texts consisting of simple and familiar **words**. Reads aloud at a beginner level. Begins to correct as fluency and understanding develop. Still needs support with new and unfamiliar words/texts. **Comprehension development:** With support, begins to locate and retrieve simple and explicitly stated information, actions, and ideas, and makes simplistic inferences about events and reasons for actions in texts. Shows a growing ability to make sense of what they read, drawing on illustrations and their knowledge of language and the world.
Writing
Physical aspects of writing: Writes symbols and digits of the correct size, orientation (including spacing) and relationship to one another. **Transcription:** Writes some lower frequency and complex words. Recalls and writes simple sentences that are dictated out loud, including simple **punctuation**. Writes sentences with different forms and adds description to their writing. **Begins to use tenses correctly. Uses subordination and co-ordination**. Uses grammatical terminology to discuss their writing. **Composition:** Writes for different familiar purposes. Considers what they are going to write before beginning, plans and writes down ideas, and uses key words including new vocabulary. Writes down what they want to say, sentence by sentence. Makes simple additions, revisions, and corrections to their writing by evaluating their writing with others and proof-reading.

8 Years

Oracy
Continued development/reinforcement. No specific age-level milestone.
Reading
Knowledge/text awareness: Develops a higher level of **phonological awareness** and draws on their understanding of relevant language constructs when decoding text. Applies their developing reading knowledge when reading **words** containing known **symbols and sounds** and recognises alternative and more complex **symbols/sound combinations**. Through reading **aloud**, begins to recognise when a text/their reading makes sense. Has an extended vocabulary of sight **words** which supports recognition of **more complex words**. Reads texts at an appropriate 'early reader' level. Begins to interact and see differences in various text genres/purposes. Knows text attributes for fiction and non-fiction texts. **Comprehension development:** Draws on varied sources of information in order to make meaning. Reflects on their reading and responds personally to what they have read by drawing on personal connections to the texts. Evaluates the books they meet and articulates views and preferences, making connections to other texts they have encountered. In non-fiction texts, locates, recognises and reproduces explicitly stated actions, events and feelings, as well as making straightforward inferences about the attributes, feelings, and motivations of main characters. Locates two or three pieces of information from text and makes straightforward inferences to provide factual explanations and the order of events. Begins to recognise the author's language choices.
Writing
Physical aspects of writing: Writes with legibility, fluency, and consistency. **Transcription:** **Punctuates direct speech**. Chooses nouns or pronouns appropriately. Expresses time and cause appropriately. **Extends the range of sentences with more than one clause by using a wider range of conjunctions**. Uses and understands grammatical terminology accurately and appropriately. **Composition**: Writes down their ideas with a reasonable degree of accuracy and effectiveness. Understands how writing can be different from speech. Plans their writing using a variety of strategies. In narratives, creates settings, characters, and plots. In non-narrative material, uses simple organisational devices. Drafts and writes, using a progressively varied and rich vocabulary and an increasing range of sentence structures. Evaluates and edits their writing, assesses the effectiveness of their own and others' writing, suggesting improvements and proposing changes to grammar and vocabulary. Understands how to write for a variety of purposes and audiences.

9 Years

Oracy
Uses a range of regular and irregular grammatical word endings, and uses complex grammar and sentences to clarify, summarise, explain choices, and plan. Uses complex conditionals. Uses formal language when appropriate. Understands conversation rules (when to talk and when to listen). Uses intonation linked to grammar to help make sense of information. Infers meanings and reasons and makes predictions.
Reading
Knowledge/text awareness: Interacts with larger units of text. Decodes more effectively and reads more fluently due to the automaticity of drawing on **phonological** knowledge and relevant decoding systems. Reads for more sustained periods of time with familiar genres of text. Continues to develop vocabulary. Reads texts at an appropriate 'developing reader' level. This increase in fluency and automaticity supports increased comprehension. **Comprehension development:** Is increasingly aware of language choices and basic figurative language which convey additional meaning or are appropriate for specific audiences or purposes. Is more confident in expressing opinions including likes, dislikes, and challenges, as well as responding to the questions and listening to the views of others.
Writing
Physical aspects of writing: Writes down their ideas quickly. **Transcription:** Extends and joins parts of their text appropriately. **Ensures that tenses are consistent**. **Composition:** Revises their own text, with support, to link and develop ideas more coherently.

10 Years

Oracy
Critically considers multiple perspectives around an issue to pursue the most reasonable solution. Uses the discourse of reasoned argumentation to discuss stories or texts, and develops an argument schema. Formulates counter arguments.
Reading
Knowledge/text awareness: Uses a fuller range of language decoding systems. Effectively reads silently and self-monitors their reading. Copes with more demanding texts and reads for longer periods of time. Fluently reads texts containing familiar words and from familiar genres. **Comprehension development:** Locates and distinguishes relevant information within dense or more complex tables and makes inferences about logical connections between information. Integrates textual and visual information to form evaluations and generalisations about the content. Locates and distinguishes significant actions and details embedded across the text and makes inferences to explain relationships between intentions, actions and events. Effectively uses appropriate information books and materials for straightforward reference purposes, but still needs help with unfamiliar material.
Writing
Physical aspects of writing: Writes legibly, fluently and quickly so that problems with forming symbols do not impede their writing. Knows which standard and form of handwriting is appropriate for a particular task. **Transcription:** Writes accurately most words encountered so far, and writes words that have not yet been encountered by using any rules of writing they have learnt. Writes using grammar and **punctuation** which is broadly accurate. Is aware of synonyms. Recognises vocabulary and structures that are appropriate for formal speech and writing. Conveys complicated information concisely through writing. Uses and understands grammatical and other linguistic devices accurately and appropriately. **Composition:** Plans their writing by identifying the audience and purpose and selecting an appropriate form. Uses similar writing as a model and draws from their reading and research. In their writing, selects appropriate grammar and vocabulary and knows how these choices affect meaning. Integrates dialogue in narratives. Evaluates and edits their writing, and proposes changes to vocabulary, grammar and **punctuation** to enhance effect and clarify meaning. Distinguishes between the languages of speech and writing and chooses the appropriate register.

11 Years

Oracy
Expresses issues and ideas using specialist vocabulary and examples. Speaks clearly, varying expression, tone, and volume to keep listeners interested. **Uses long and complex sentence structures including more sophisticated connectives to join ideas together in conversation**.
Reading
Knowledge/text awareness: Is able to cross-check across a range of decoding systems. Confidently **decodes language** in ways that supports independent reading of unknown texts and some unknown genres. Reads unknown texts aloud clearly and with increasing confidence. Reads texts that are appropriate for a moderately fluent reader. **Comprehension development:** Distinguishes and interprets different parts of a text and why they are used. Asks questions to enhance their understanding of the text and makes comparisons within and across different texts. Is more able to appreciate nuances and subtleties in text. Makes explicit connections with other reading and personal experience, such as inferring characters' feelings, thoughts and motives from their actions, and justifying their inferences with evidence. Evaluates visual and textual elements to discuss the viewpoint of the author. Is comfortable with reading both silently and aloud to others. Reads a wide range of texts independently.
Writing
Transcription: Controls sentence structure consciously in their writing and understands why sentences are constructed as they are. **Composition**: Selects more nuanced vocabulary and grammar to reflect their understanding of the audience and purpose of their writing. Begins to organise longer texts into sections for clarity.

12 Years

Oracy
Continued development/reinforcement. No specific age-level milestone.
Reading
Knowledge/text awareness: Has strong vocabulary and **phonological awareness** which may be reaching the level of full automaticity, allowing them to access most texts appropriate for fluent readers. Is developing confidence in tackling new genres independently. Shows evidence of growing enthusiasm for a wider range of reading material that they self-select. **Comprehension development:** Draws on sources to investigate a topic independently and disseminates appropriate information found in texts. Distinguishes between statements of fact and opinion across a range of texts. Comments on how organisational structures and language, including **figurative** language, are used to contribute to meaning and how these impact on the reader. Expresses views formed from reading, explaining, and justifying these views.
Writing
Continued development/reinforcement. No specific age-level milestone.

13 Years

Oracy
Continued development/reinforcement. No specific age-level milestone.
Reading
Knowledge/text awareness: Decreases conscious reliance on decoding systems and significantly increases automaticity. As confidence increases and vocabulary references continue to broaden, fluency and accuracy becomes of primary focus. Reads texts appropriate for a fluent reader. **Comprehension development:** Develops critical awareness as a reader, analysing how the language, form and structure are used by a writer to create meanings and effects, and developing an appreciation of how particular techniques and devices achieve the effects they do. Is more able to question and/or admire aspects of content, form and function.
Writing
Continued development/reinforcement. No specific age-level milestone.

14 Years

Oracy
Presents ideas and issues convincingly using a range of techniques for impact (e.g. **rhetorical questions**, appeals to listeners, gestures). Sustains a convincing point of view, anticipating and responding to other perspectives (e.g. in role or debate). Identifies how ideas are presented to promote a particular viewpoint (e.g. use of persuasive language, ignoring inconvenient facts, reaching illogical conclusions). Understands the difference between the words and style of talk used with friends and the different style of talk needed in the classroom.
Reading
Knowledge/text awareness: Automatically draws from a range of vocabulary and **language decoding systems** to read fluently and to accurately recognise/represent the emotion intending by the author. In addition, has developed independent strategies to effectively and independently increase their fluency and comprehension. **Comprehension development:** Sees and critiques viewpoints represented within a text. Analyses and critiques a range of genres. Evaluates evidence drawn from a variety of information sources. Explains and discusses their understanding of what they have read in a variety of ways appropriate for a range of audiences.
Writing
Physical aspects of writing: Writes legibly at length. **Transcription: Knows and understands the differences between written and spoken languages, including those associated with formal and informal registers and between the standard written version of their L1 and other versions**. Uses the standard written version of the L1 confidently in their own writing. Draws on new vocabulary and grammatical constructions from their reading and listening and uses these consciously in their writing to achieve particular effects. Discusses their writing with precise and confident use of linguistic and literary terminology. **Composition:** Writes appropriately in different genres, for different audiences, and develops personal voices. Begins to set appropriate mood and tone for their pieces. Understands the relationships between words, nuances in meaning and ability to use **figurative language**. Writes accurately, fluently and effectively at length. Writes for a wide range of audiences (including narrative and non-narrative texts). Summarises material. Includes supporting ideas and arguments in their writing. Draws on knowledge of literary and **rhetorical devices** to enhance the impact of their writing. Reviews their writing and amends for accuracy and effectiveness. Identifies most of their own grammar, spelling, and **punctuation** errors.

10.1 Literacy Annex: Reading speed (fluency)

Background

UNICEF rightly differentiates comprehension, accuracy and fluency (MICS UNICEF, 2017). One principal aim of the development of reading is comprehension. This can of course include derivation of literal, logical or analogical meaning of text, as well as higher level skills and cognition associated with appreciating deeper signification (Fisher & Frey, 2012; Shanahan, Fisher & Frey, 2012). Critical reading at a high level – appreciation of use of language forms, literary devices, and so on – is an important elaboration of literacy (Fisher op cit; Royle & Bennett, 2009), but is not central to the discussion here. For a learner to have a high chance of progression to advanced and higher education, critical reading is important, and we do not exclude it from being available to displaced learners. What we are concerned with in this annex is the role and importance of fluency and specifically, reading speed expressed as 'words per minute'.

Discussion

Comprehension, accuracy and fluency are distinct, but related. Fluency comes with high automaticity in reading (Torgesen, Rashotte & Alexander, 2001; Hook & Jones, 2002). High automaticity frees up working memory to allow concentration on meaning (Abadzi, 2011). High reading speed does not guarantee comprehension, in fact an undue focus on 'speed reading' can depress comprehension (Miyata et al., 2012), so pursuit of reading speed at the expense of parallel development of comprehension and accuracy is educationally sub-optimal. However, higher speeds of reading (and writing) correlate with higher overall educational attainment (Roaf, 2003; Seabra et al., 2017) and the mechanisms are compelling:

1. In reading faster, young people have greater access to a wide range of materials, broadening their experience and knowledge.
2. In reading faster and with greater automaticity, young people can focus more on nuance, text features and meaning. The greater exposure to language forms and text types enhances cognition and increases cultural capital.
3. In writing faster, with greater automaticity and in greater volume, young people externalize their thinking to a greater extent, enabling reflection on and refinement of thought.
4. In writing faster, and in greater volume, a young person's thoughts are more available to teachers and others, allowing more feedback, discourse and support.

These are important mechanisms, and explain cognitive development as well as productive relations with others, including educators. Reading speed is subordinate to comprehension since comprehension is the ultimate objective, but it is not irrelevant to important aspects of human development.

Iceland recently has introduced national tests of reading speed, used three times per year in primary schools. These tests have been welcomed by schools, who use the data from the tests to identify children whose reading has plateaued or gone backwards, and to gain a sense of the rate of improvement and development of each child.

UNICEF rightly has accessed research which emphasizes the differing complexity of different written languages, and the impact that this has on L1 (first language) acquisition and on reading speed. It also rightly has recognised that certain communities do not have access to L1 education experience, and so have to acquire reading in L+. Whilst this adds complexity in setting expectations (not least in identifying parallel texts in order to establish recommended general norms), and suggests that reading speed (fluency) should be ignored in favour of comprehension, we wish to argue an alternative perspective here.

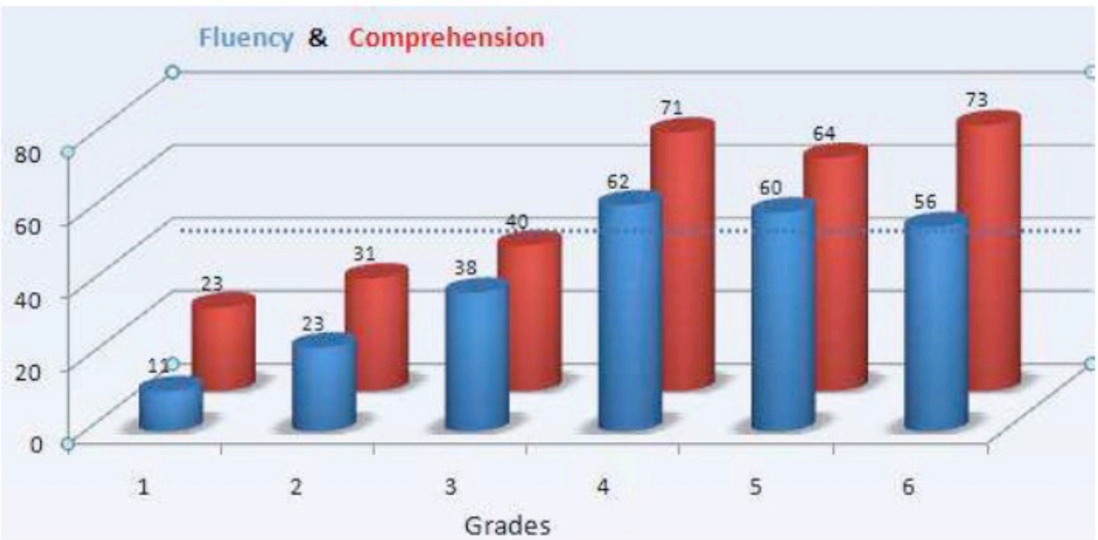
Firstly: different norms can be established for different language contexts, and for L+ versus L1 acquisition. Norm tables can readily be used to identify children at risk. The assessment is quick, and can be completed with precision.

Secondly: whilst human cognition is strongly linked to language structures and language acquisition (and therefore heavily contextualized in a specific language setting) for international mobility, higher levels of cognitive ability are favourable for individuals. This suggest 'stretch' and wide experience, facilitated readily in some language settings (which for example include statements of complex causal relationships) and more challenging (but essential) to deliver in others.

Thirdly: reading speed is readily understood by teachers, adults and young people. It is an objective measure, assessment is readily completed, and an understandable outcome (words per minute) is generated from the assessment. These are important qualities.

Support to increase reading speed in those young people with depressed facility can be rewarding and engaging for the child, as well as easily supported by adults or others. The purpose of the activity is clear and unambiguous; utility therefore is high, along with fidelity of implementation. Accuracy can be attended to alongside a focus on increasing speed – they are not mutually exclusive. Activities for elevating speed of reading in those falling below norms of reading speed also simultaneously can be focused on increasing comprehension. Helen Abadzi (2011, p.15) posits some average indicative norms (Figure 8):

Figure 8: Average fluency and comprehension rates in 17 selected FTI partner countries



But these could be generated for specific linguistic communities and contexts. The key outcome is high benefit in terms of exposure to knowledge and the acquisition of cultural capital (Table 14):

Table 14: The number of words read daily multiplies into many words per year and pays off

Test Score – Percentile	Minutes Reading Per day	Words Read per Year
98	67.3	4,733,000
90	33.4	2,358,000
70	16.9	1,168,000
50	9.2	601,000
30	4.3	251,000
10	1	51,000
2	0	-

Source: Anderson, Fielding, and Wilson (1988)

Recommendations

1. Develop a table of language-specific age-specific norms for those supporting learners. These also can be used in peer- and self-diagnosis.
2. Use research on comparable texts (Hahn, 2006) in developing assessment instruments for self- and teacher review.
3. Use a progression scale early/emergent to mature/experienced based on a small series of steps or benchmarks (Abadzi, 2011).
4. Develop a clear statement to include in programmes, support materials, autodidact materials explaining with clarity, simplicity and precision the relationship between comprehension, accuracy and fluency.
5. Self-motivated wide reading is related to high attainment – this frequently is rather reductively labelled 'Reading for Pleasure' (DfE 2012). Accompanying the Framework should be a clear statement on encouraging wide reading/reading for pleasure (DfE op cit) and the assets of critical reading for older youths.

11 Appendix 1: Maths and Science framework developer biographies

Framework development leads

Tim Oates CBE

Director of Assessment Research and Development, Cambridge Assessment (University of Cambridge Local Examinations Syndicate)

Tim Oates is Group Director of Assessment Research and Development at Cambridge Assessment, focusing on national and international research on assessment and measurement. In 2010 he published 'Could do better' which laid down the principles for the review of the National Curriculum in England. He was chair of the Expert Panel for Review of the National Curriculum in England. Emerging from this review, subsequent research on the quality and function of textbooks and other resources has been taken up around the world and discussed at two international summits on learning resources. He chairs various curriculum groups for the Department for Education in England. He has published widely on assessment and curriculum issues, and routinely provides briefings and advice to UK and other governments. He has worked with OECD on curriculum matters and is leading a new UNICET project on a curriculum framework for displaced children. He is Fellow of Churchill College Cambridge and in 2015 received a CBE for services to education.

Dr Martin Johnson

Cambridge Assessment, Assessment Research and Development Division

Dr Johnson is a Senior Researcher at Cambridge Assessment. He is also a member of the Centre of Global Human Movement at Cambridge University, a Fellow of the International Society for Design and Development in Education, and an Executive Member of the British Association for International and Comparative Education. The focus of much of his work is on the interaction between assessment, learning and curriculum issues, often with an international focus. Projects have ranged across academic and vocationally related contexts and investigated assessment issues in diverse sectors (e.g. primary through to post-compulsory education). His general research interest is on how to better understand assessment as enacted practice. This has involved using assorted qualitative research methods to gather the perspectives of those involved with, or affected by, assessment.

Tori Coleman

Cambridge Assessment, Assessment Research and Development Division

Tori's background is in Psychology and Education, she has a BSc in Psychology from the University of Bath, and an MPhil in Education (Psychology and Education) from the University of Cambridge focusing on Developmental Coordination Disorder (DCD). She is currently a researcher at Cambridge Assessment where she is involved in curriculum and assessment related research. She has worked on a range of projects relating to educational taxonomies, accessibility of examination papers, construct validity, and curriculum mapping. She is part of the team leading the Curriculum development for the UNICEF-Cambridge collaborative project, being involved in the early work including the feasibility mission to Cox's Bazar in Bangladesh.

Dr Sinéad Fitzsimons

Cambridge Assessment, Assessment Research and Development Division

Dr Fitzsimons is a Research Officer at Cambridge Assessment in the area of Curriculum and Development. She is also a member of the Centre of Global Human Movement at Cambridge University. She has worked on many international curriculum development projects especially in post-conflict and divided societies. This has involved curriculum and resource development, monitoring and evaluation and teacher training. She is also an Executive Board member for the EU Association of History Educators (EUROCLIO). Her PhD research, completed at Queen's

University Belfast, focused on the influence of curriculum on how young people view and develop their sense of identity in post-conflict and/or divided societies. Before completing her PhD, Fitzsimons taught secondary History for ten years in Belgium, Northern Ireland and England.

Dr Jackie Greatorex

Cambridge Assessment, Assessment Research and Development Division

Jackie holds a Master of Education from University of Bristol. In her PhD (University of Derby), she managed the development of descriptions of different levels of learning in health-related degrees, underpinned by psychology, andragogy and curriculum theory. Since joining Cambridge Assessment, she researched a range of assessment topics including examiners' cognition and what makes marking reliable. Jackie is a Principal Research Officer and leads the Research Division's Education and Curriculum team. The work is wide-ranging and open to include all ages, subjects (academic or vocational), jurisdictions, and situations. This builds on her PhD studies and gives the opportunity to research a variety of key education and curriculum matters. Her work has included studying the teaching approaches in Chemistry, researching how a mathematics curriculum is organised in education centres and undertaking curriculum mapping as part of curriculum development.

Maths

Rachael Horsman

Cambridge Mathematics, University of Cambridge

Rachael leads the writing and strategy development for Cambridge Mathematics. Following time spent teaching and travelling in Asia, she took a Maths degree at the University of Bristol and La Universidad de Murcia, Spain, and then completed a PGCE at the University of Wales, Swansea. After this she taught mathematics for 13 years in Peterborough, Cambridgeshire and Hertfordshire, from primary to post-16, including Further Maths, IGCSE and STEP. Rachael has held a variety of positions including advanced skills teacher, specialist leader of education, head of department and assistant head, working in a variety of contexts including a high performing grammar school, a rural comprehensive and an inner city school in very challenging circumstances. These roles have included mentoring trainees, NQTs and subject leaders, leading professional development across schools with teachers and classroom assistants, running local authority training, writing and developing schemes of work and resources as well as working with a wide variety of institutions and students. Rachael has run and designed teacher training workshops and curriculum development projects in the UK and abroad, and has authored several resource/text book publications. She is in the process of completing an MPhil at the Centre for Research in Mathematics Education investigating the structures of knowledge that teachers bring to the classroom and how the Cambridge Maths Framework can support and develop Maths knowledge for teaching.

Dr Lynne McClure

Cambridge Mathematics, University of Cambridge

Before setting up Cambridge Mathematics, Lynne was Director of the prestigious NRICH project based in the University of Cambridge's Centre for Mathematical Sciences, and also served as Principal Investigator on the Department for Education-funded innovative A-level project Underground Maths. Previous roles included headship of a small primary school, Principal Lecturer and Course Leader at Oxford Brookes and Edinburgh Universities, Principal Examiner and international consultancy. Lynne chaired the recent English National Curriculum for Mathematics team and she is a member of the Advisory Committee on Mathematics Education. Lynne is a Chartered Maths Teacher and an invited Fellow of the Institute of Mathematics and its Applications, a trustee of National Numeracy and has been President of the Mathematical Association and Executive Chair of the International Society for Design and Development in Education (ISDDE).

Professor Geoffrey Wake

Centre for Research in Mathematics Education, University of Nottingham

Geoff Wake is Professor of Mathematics Education at the University of Nottingham where he leads the Centre for Research in Mathematics Education. His research focuses on the teaching and learning of applications of mathematics and design-based research of curriculum, materials and assessment across all phases. He has been involved in developing a number of national qualifications for use by students in the tertiary phase. Geoff has collaborated extensively with European and Japanese researchers and the Centre also has strong connections with colleagues in the United States. He is currently working extensively with teachers in Further Education colleges researching teaching to improve student assessment outcomes and working to develop mathematics courses and assessment for new pre-vocational qualifications. He is also researching the use of didactical tools in the teaching of mathematics in Japan.

Darren Macey

Cambridge Mathematics, University of Cambridge

Darren spent nearly 10 years teaching secondary Maths before he joined the Oxford, Cambridge and RSA examination board in 2014 where he worked on the redevelopment of A Level Mathematics. Darren now works for Cambridge Mathematics on the 'statistics' content in the Cambridge Mathematics Framework. He is currently studying for a Master's degree at the Faculty of Education at Cambridge University and is part of their Mathematics Education Research Group. Darren's research interests include mental models of statistical concepts and developing statistical reasoning. He is an ambassador for the Royal Statistics Society and a member of their 'Teaching Statistics' special interest group committee. He also writes about Maths teaching and assessment and has co-authored the pedagogy book for teachers 'Teaching Statistics'.

Tabitha Gould

Cambridge Mathematics, University of Cambridge

Before joining the Cambridge Mathematics team Tabitha designed resources and professional development within the post-16 project Underground Mathematics, and as part of the Secondary Maths team at NRICH. Prior to this she taught mathematics in a local secondary school, having the unusual opportunity to teach students in mixed ability groupings all the way from year 7 up to GCSE. In her role at Cambridge Mathematics she is developing learning and teaching trajectories for 'number'.

Dr Melise Camargo

Cambridge Assessment International Education, Professional Development team

Melise has a background in teaching Mathematics in schools in Brazil where she also worked for the Ministry of Education, delivering teacher training in several states. Melise joined Cambridge International in September 2016, working in the Curriculum Programmes team, involved in several education reform projects and the redevelopment of the Primary & Lower Secondary Mathematics Curriculum. Melise has also been responsible for a large-scale teacher training project in Macedonia, funded by the European Commission, to train teachers in the uses of formative assessment. Melise is currently the Training Materials Manager, responsible for overseeing the production and quality of all training materials for Cambridge International's face-to-face training events. Melise has completed a PhD in formative assessment in mathematics at the University of Cambridge and has also been a supervisor and examiner on the Postgraduate Certificate in Educational Examinations and Assessment.

Dr Ellen Jameson

Cambridge Mathematics, University of Cambridge

On the Cambridge Mathematics project, Ellen designs and analyses formative evaluations of the Cambridge Mathematics Framework, reviews research in mathematics education and educational design, and collaboratively co-develops and documents their design and research practices. Previously, Ellen was a Research Associate at the Center for Research on Learning and Technology in the School of Education at Indiana University Bloomington, where her research involved social learning in STEM subjects through collaboration in computer-based simulations and games.

Paula Beverley

Cambridge Assessment International Education, Curriculum Programmes Manager

Paula has a degree in Mathematics and began her career as a primary school teacher and mathematics coordinator. She moved from teaching to publishing, working at Cambridge University Press for many years project managing and editing print and digital teaching and learning resources for primary mathematics. Whilst at Cambridge University Press, she authored 101 ways to use the Mult-e-Maths Toolbox at KS1 [Key Stage 1]. Since joining Cambridge Assessment International Education, Paula has worked on a variety of international projects, managing the development and review of a range of curricula, teacher and learner support materials and teacher training. This has included development of mathematics curricula for Macedonia and Oman, and review of primary and pre-primary curricula for Kenya and Ethiopia.

Dr Ellie Darlington

Cambridge Assessment Admissions Testing

Ellie is an Assessment Manager for Mathematics at Cambridge Assessment Admissions Testing where she runs commissions for question writing and paper construction of the BioMedical Admissions Test (BMAT), University of Cambridge entrance tests in Natural Sciences, Engineering, Economics, Computer Science and Psychology, the Test of Mathematics for University Admission (TMUA), Sixth Term Extension Paper (STEP) and entrance tests for schools and universities overseas. Her background is in mathematics education research, with a particular focus on the transition between school and university study.

Science

Ann Fullick

Consultant

Ann Fullick has a considerable range of experience in the delivery of Biology education, built on her training and expertise as a teacher and her far-ranging and extensive biological knowledge. She became involved in writing biology resources from an early stage in her career and has produced a wide variety of material with around 200 books, including some of the most widely used GCSE and A level Biology texts in the UK, along with articles and web-based resources. Internationally she has written for the Caribbean, many African countries including Uganda, Ethiopia, Tanzania, Rwanda, Nigeria and Liberia, the US and Australia. She has extensive knowledge of both developing and using Biology curricula in the UK and around the world, and of working with teachers, students, learned societies, governments and other stakeholders.

Helen Harden

University of York

Helen is a former head of chemistry. She is currently working as chemistry curriculum specialist for the University of York Science Education Group’s Best Evidence Science Teaching Project which is developing research-informed diagnostic questions. Helen has developed award winning resources and has provided curriculum consultancy to a range of organisations including the Association for Science Education, Royal Society of Chemistry and Cambridge Assessment International Education. Helen is chair of the Association for Science Education ’s 11-19 committee and a member of the Royal Society of Chemistry’s 11-19 Curriculum and Assessment Working Group.

Dr Ronald Mazorodze

University of Suffolk

Ronald has led the teaching of science and physics at GCSE and post-16 levels in the UK, Africa and the Caribbean. He is a Course Leader and Senior Lecturer in Early and Primary Studies at the University of Suffolk where he works on postgraduate courses as well. He has worked as a Science teacher trainer with various universities in the UK. He recently published a book on physics problem with Professor Michael Reiss (UCL-IOE) where he completed his doctoral studies.

Professor Robin Millar

University of York, Professor Emeritus

Robin Millar is Emeritus Professor of Science Education at the University of York. Following a BA in Natural Sciences (Cambridge) and a PhD in medical physics (Edinburgh), he taught physics and general science for 8 years in comprehensive schools before moving to York to teach on the science PGCE and masters' programmes and supervise PhD studies. His research interests are in teaching and learning science at secondary school level, science curriculum design and development, and the assessment of science learning. He has directed several large research projects and played a leading role in several major curriculum development projects in England. He was President of the European Science Education Research Association (ESERA) from 1999-2003 and of the UK Association for Science Education in 2012, and a member of the Science Expert Group (SEG) for the OECD PISA studies in 2006 and 2015. In 2015 he was made an OBE for services to science education

Marc Neesam

Cambridge Assessment International Education, Curriculum Development Team

Marc Neesam is a Curriculum Programmes Manager at Cambridge International. He is a science specialist with Chemistry degrees from the University of Nottingham and the University of York. He is an experienced curriculum developer, specialising in science, technology and technical subject curriculum design, with a particular focus on the process and principles of curriculum design. He has experience on a range of international projects relating to curriculum and assessment, and has been involved in curriculum review, development and design in a variety of contexts. He previously worked at the Royal Society of Chemistry where he was involved in the development of chemistry curriculum and resources for a variety of age ranges. He has over five years of primary teaching experience including school level curriculum design. He is actively engaged in professional networks in science education including actively contributing to the work of the Association for Science Education in the UK as Chair of the ASE International Group.

Professor Jonathan Osborne

Stanford Graduate School of Education, Professor Emeritus

Professor Osborne is the California Chair of Science Education at Stanford University, USA. He started his career teaching physics in London schools before joining King's College London in 1985 where he worked until 2008. He has undertaken research into the nature of science and argumentation, attitudes to science and science education for the public understanding of science. He has worked on four major projects in argumentation. The first from 1999-2002 was on 'Enhancing the Quality of Argument in School Science Education'. From this he developed the IDEAS (Ideas, Evidence and Argument in Science Education) materials to support teacher professional learning funded by the Nuffield Foundation. From 2007-2010 he was co-PI on the project 'Learning to Teach Ideas, Evidence and Argument in School Science' which explored how to build teachers competency with the use of this pedagogy in four schools.

Dr Judith Roberts

Cambridge Assessment International Education, Curriculum Development Team

Judith is Head of Primary and Lower Secondary for Cambridge International, with overall responsibility for the development of primary and lower secondary curricula. In 2019, she oversaw the introduction of four new subjects to the programme. She qualified as a secondary science teacher and taught GCSE sciences and A level Biology from 2010-2013. She retains a role as supervisor on Cambridge University's parasitology component of 2nd year biology of disease for medical students. She holds a PhD from Cambridge University in Infection and Immunity. Her MEd, also from Cambridge, focused on A level biology practicals.

Dr Tony Russell

Independent science education consultant

Ten years of primary teaching, including three as DHT, led to a science lectureship in Botswana, training primary teachers. This inspired his PhD study of how science education had developed in Botswana. He focused on the comparison of policy and practice and reasons for the miss-match. Tony returned to UK schools and then spent five years as an LA Science Advisor, before APU (Science) research at King's College, which formed the foundation of the National Curriculum and SATs process. He evaluated the KS3 science SATs and also administered the 3 year TEMPUS project to reform science teacher education in Slovenia, where he was Senior Lecturer at Ljubliana University for a term. Tony has authored five sets of primary science books (totalling 40) and been consultant in 13 countries. He have been a researcher at the Institute of Education in London for the last 17 years..

David Shakespeare

Independent science education consultant, Square 2 Learning

An experienced teacher and adviser, David Shakespeare is an independent consultant who supports teachers and schools, local authorities, Government educational projects and programmes (including England's Standards and Testing Agency), the 'learned' societies, examination boards, and others. He works in science education at all levels from primary to secondary and higher education, and in all aspects of teaching and learning, including the development and implementation of new approaches to curriculum and assessment in the UK and elsewhere. He is a Fellow of the Chartered Institute of Education Assessors and a life-long member of the Association for Science Education

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