A knowledge-rich curriculum underpinned by the science of learning

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Contents

1. Preamble

The scientific literature on human learning (the science of learning) shows that learning is facilitated by teaching knowledge in a carefully structured way. A knowledge-rich curriculum supports the work of teachers by laying out the knowledge to be taught in coherent, carefully staged sequences. This paper provides some background from the science of learning, to support curriculum writers to produce a knowledge rich curriculum, and to develop resources for teachers to support its implementation.

It is our intention to develop from this background paper, information for inclusion in the *Aims and Purposes* of the curriculum, outlining the principles and reasoning informing the curriculum design. This should include overarching implications from the science of learning for teachers' practice, as well as implications specific to each subject, based on the nature of the knowledge in the discipline with which it is aligned (see 2.2). An introductory section for each learning area should describe how the design for that learning area has been conceptualised, and why. This will assist teachers to implement the curriculum effectively.

In most cases, the science of learning does not speak directly to what knowledge, or how much knowledge, should be specified in a knowledge-rich curriculum[i]. Nor does it tell us what it means to be educated. The selection of content for a curriculum is based both on curriculum philosophy and considerations specific to each subject or learning area. It would therefore be beneficial to include in a preamble to each learning area, a rationale for the knowledge that has been included.

This background paper needs to be followed up with additional resources for the curriculum writers for each learning area, following responses to this initial paper. It is our intention to develop the following resources:

1. **Further written information, presentations and opportunities for discussion**
   Ongoing engagement with writers will help to ensure alignment to the curriculum principles that emerge from the science of learning. It will also enable the writers to create connections and cohesion across curriculum areas, while also ensuring that each reflects the nature of the discipline from which its content is drawn.

[i] In some subjects, the science of learning does have implications for the knowledge and skills that should be included in a curriculum. Early literacy and mathematics are two examples.

2. **Conceptualisation of the key competencies**

   The key competencies are a legacy of the 2007 New Zealand Curriculum. The competence-based approach taken to that curriculum contrasts in many ways with a knowledge-rich approach, aligned with the science of learning.[1] Even so, the key competencies can be coherently included in a knowledge rich curriculum in a way that is guided by the science of learning. Work should therefore be undertaken to situate the competencies in the new approach. This should include an explanation of how the competencies can be integrated into teaching and the wider school culture. While this paper includes some initial work in that regard (See 6.0), further work is needed.

   To support fidelity of implementation a further range of resources must also be developed for teachers:

1. **How to use the curriculum to develop programmes of learning in schools**

   The rollout of the curriculum must be accompanied by documentation and professional learning programmes to assist teachers and school leaders to translate the national curriculum into programmes of learning in their schools. This should include developing teachers' understanding of the connections between curriculum and pedagogy.

2. **Curriculum resources**

   Second tier resources must be developed to enable teachers to translate the curriculum into teaching practices and learning tasks for students.

2. What is a knowledge-rich curriculum

A knowledge-rich curriculum describes the knowledge that all young people are entitled to be taught at school. It lays out the knowledge to be taught in sequence of stages. For the New Zealand curriculum these stages are defined year-by-year, across five broad phases: Years 1-3; Years 4-6; Years 7-8; Years 9-10; and Years 11-13.

2.1 Characteristics of a knowledge-rich curriculum

According to the Australian Education Research Organisation:

> *A knowledge-rich curriculum prioritises and explicitly outlines the subject knowledge and related skills that students should be taught and develop at each stage of their schooling. It is selective, coherent, carefully sequenced and clear.*[2]

The characteristics is of *selectivity*, *coherence*, *carefully sequencing* and *clarity* are each elaborated below.

2.1.1 A knowledge rich curriculum is selective

The content of a knowledge rich curriculum is chosen purposefully for each subject. No curriculum can cover everything. A curriculum that attempts to include too much is overwhelming and attempts to implement it are inevitably superficial.

A curriculum that aims to develop the personal excellence of young people needs to be designed for deep learning. That means enabling teachers to create multiple opportunities for students to engage with new knowledge and skills, to form coherent cognitive schema (see 3.3.1). A knowledge rich curriculum, therefore, needs to select the knowledge that is relatively most important. Decisions regarding the relative importance of content are guided by two main principles:

- The curriculum should include the important concepts and practices of the disciplines that each subject draws upon.
- Curriculum content should be selected according to its current and future significance for students. This includes knowledge and skills critical to further learning in a subject.

To some extent, the knowledge and skills most important to the development of students' personal excellence varies between individual students. A national curriculum must therefore leave space for teachers to make decisions about content selection based on the interests and backgrounds of their students.

2.1.2 A knowledge rich curriculum is coherent

In a coherent curriculum, subjects based on universal disciplines (see 2.2) are foundational. The content of each subject is written so that knowledge, skills, competencies, attitudes and values are embedded within them in disciplinary-relevant ways.

The complexity of a curriculum is determined by the number of interacting elements that teachers need to bring together. If the elements are presented in isolation, the complexity of implementing the curriculum is increased. A coherent curriculum reduces complexity for teachers by interconnecting content across topics, subjects and stages of learning. When relevant interconnections between related knowledge elements and skills are made explicit, they become mutually reinforcing.

2.1.3 A knowledge rich curriculum is carefully sequenced

A curriculum must enable students to develop deep and broad knowledge over time. Teachers can guide this process by building on their prior learning with gradually increasing complexity. Cognitive load (see 3.1) is reduced when learning is scaffolded. Motivation is increased when the level of challenge is slightly in advance of a student's current level of knowledge or skill. A national curriculum must therefore be sequenced to support appropriate scaffolding and motivation.

2.1.4 A knowledge rich curriculum is clear

A clear curriculum explicitly describes the knowledge and skills to be taught in each subject, at each stage of learning.

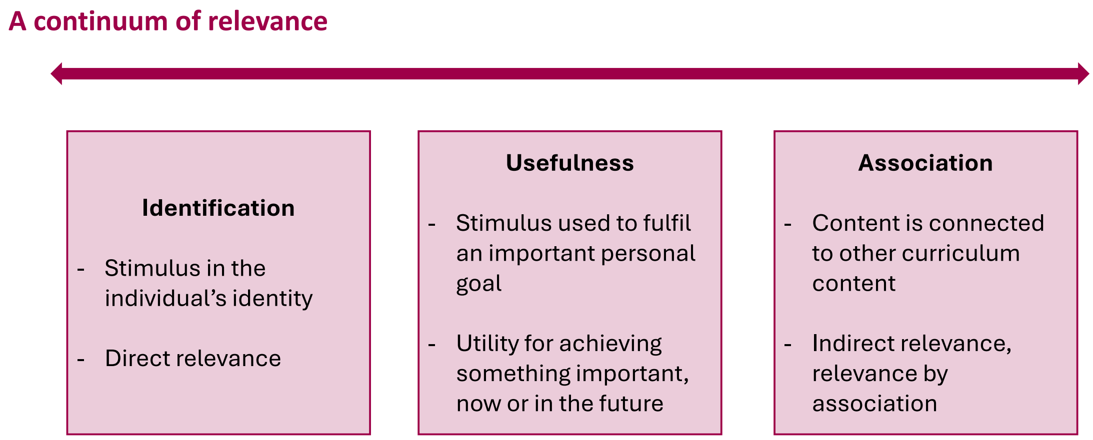
2.2 Why take a disciplinary approach?

Much of the knowledge to be included in the curriculum will be selected from universal disciplines. The universal disciplines have been developed and improved over time, often by scholars in academic communities and institutions. They continue to be developed by experts from many nations and cultures discussing and debating their ideas and perspectives in a spirit of open inquiry. These disciplines are called 'universal' because they do not belong to any one culture, but to all.

In a knowledge rich curriculum, the universal disciplines are recontextualised as school subjects.[3] The knowledge specified for each subject is structured and sequenced so that skilled and knowledgeable teachers can make it accessible to students. The structures and sequences also take account of scientific research on how students learn. In some cases, especially early literacy, this research describes an explicit order in which knowledge elements and skills are best sequenced. In many cases, the research elucidates the more general principle that knowledge must be secure in long-term memory before it can be used to support further learning (see 3.3).

2.2.1 The relevance of disciplines

There are different ways of thinking about the relevance of curriculum content to students. Some knowledge is relevant because it directly relates to aspects of students' identities, such as their interests, aptitudes or cultures. Knowledge may also be relevant because it is useful to achieve personal goals or more general goals such as employability. Knowledge that helps to cultivate higher-order thinking or creative capabilities is also relevant through this utility. Some knowledge has indirect relevance through association with other curriculum content, either because it is prerequisite to that learning or because it is related to it in ways that helps students form coherent cognitive schema (see 3.3.1). Disciplinary knowledge frequently satisfies all three of these criteria.



2.2.2 The curriculum learning areas

In the curriculum, school subjects will be grouped with related subjects into eight learning areas. While the knowledge to be taught to students is subject specific, bringing related subjects together into learning areas enables teachers use contexts to support the teaching of more than one subject. Making connections between subjects helps students develop their understanding of each.

Some learning areas in this curriculum are derived from disciplines that create and refine knowledge, based on observations of the natural world and of human societies and cultures.

Science, supported by mathematics and statistics, brings together subjects based on disciplines concerned with the production of knowledge about the natural world. The social sciences, and health and physical education are based on disciplines concerned with knowledge production about the human world.

The arts, English, and learning languages comprise subjects derived from disciplines concerned with communication and cultural expression, and with the production of knowledge about these things. They enable students to understand, enjoy, create, and critique cultural artifacts, including literature, music, dance, drama, and visual arts.

All curriculum subjects equip students with knowledge that enables them to engage in critical and creative thinking. Knowledge is the raw material for authentic critical thinking and creativity (see 3.5).

2.3 Powerful knowledge

Sociologist of education Michael F.D. Young described disciplinary knowledge as 'powerful'.[4] Powerful knowledge provides students with the cognitive tools they need to understand the world they live in, and to critique their societies. In combination with social and emotional development, powerful knowledge enables young people to thrive culturally and economically, and to be active democratic citizens.

Students from affluent backgrounds often have more experience of powerful knowledge through their families and communities than those from less advantaged backgrounds. This can perpetuate social inequality. It is, therefore, especially important that students who lack access to powerful knowledge in their lives outside of schooling are taught powerful knowledge at school.

Powerful knowledge can be abstract and seemingly disconnected from students' lives and experience, especially for those from socioeconomically disadvantaged families and communities.[5] Teachers can help all students connect powerful knowledge to their own lives and experiences. To do so effectively and equitably, though, teachers must have sound understanding of that knowledge themselves. They must also use effective teaching methods.

One element of effective teaching is to take account of cognitive factors that make learning discipline-based subjects challenging for many students (see 2.5.2). Another is to ensure that classrooms are managed in a way that provides the social and emotional contexts that support learning.

Effective teaching must take account of socioeconomic factors that can make powerful knowledge more accessible to some students than to others. Teachers can make disciplinary knowledge accessible by using students' direct experience as a starting point. This can make disciplinary knowledge inviting and less intimidating to students. However, the ultimate objective is to take them well beyond the familiar.

The subject knowledge selected for this curriculum is coherently organised and advances progressively, year by year. The selection is guided by the relevance considerations in the diagram in 2.2.1 above. It is designed to enable teachers to use their professional expertise to plan and deliver that knowledge. The curriculum will support teachers to sequence and pace their teaching so that each stage is securely learned before proceeding to the next. Teaching in this way helps students to manage the cognitive load associated with learning.

Powerful disciplinary knowledge develops students' understanding of abstract concepts. Guided by a knowledge-rich curriculum and taught well, it awakens their curiosity. It opens a window into cultures other than their own, into the past, into powerful technology and human ingenuity, into great art and literature, into the nature of life and of the universe itself.

2.4 Mātauranga Māori

[We need to seek advice on how mātauranga Māori relates to powerful knowledge and how it will be addressed in the curriculum.]

2.5 Two kinds of knowledge

At the most general level, human knowledge can be distinguished into two types: Biologically primary knowledge, and biologically secondary knowledge.[6]

2.5.1 Biologically primary knowledge

Biologically primary knowledge is knowledge that human brains have evolved to acquire. For the most part, it does not have to be explicitly taught. It is learned, without apparent effort, by interacting with the world and with other people.

Oral language is an important example of biologically primary knowledge. Provide they can hear and are spoken to, young children pick up whatever language is spoken around them without anyone explicitly teaching them. Other biologically primary knowledge includes facial expression and recognition, the ability to concentrate, social interaction, and some kinds of thinking.

How well children acquire biologically primary knowledge depends on the quality of the interactions they have with their environments and with other people.[7] At school, students are assisted to acquire biologically primary knowledge when school and classroom environments ensure high quality interactions with teachers and peers. Individual and collaborative learning activities, the structure of classroom and school life, and day-to-day social interactions, are all vehicles for acquiring and enhancing biologically primary knowledge.

Although biologically primary knowledge is mostly learned without being explicitly taught, it is often beneficial, and sometimes necessary, to use explicit teaching methods to support students to acquire biologically primary knowledge. This is especially so if students are not experiencing the rich interactions needed to acquire biologically primary knowledge outside of school.

Overuse of screen technology, especially with young students, may compromise acquisition of biologically primary knowledge.[8,9] If screen time significantly displaces the high-quality interpersonal interactions needed to acquire oral language, social skills, and the ability to interpret facial and bodily cues, it may impair the acquisition of these skills.

2.5.2 Biologically secondary knowledge

Biologically secondary knowledge has been developed by human cultures over time. It includes the powerful knowledge of discipline-derived subjects in the learning areas of the curriculum. Unlike biologically primary knowledge, human beings have not evolved to acquire biologically primary knowledge. It takes effort to learn. It must be explicitly taught by skilled and knowledgeable teachers to be learned reliably.

Learning biologically secondary knowledge relies on short-term working memory (see 3.0). Working memory has a very limited capacity and information held in it is rapidly forgotten unless it is actively maintained. These properties of working memory make learning biologically secondary knowledge effortful and challenging. Biologically primary knowledge is learned without the extensive involvement of working memory.

The distinction between biologically primary and biologically secondary knowledge is illustrated by comparing the acquisition of oral language with the learning of literacy. Oral language is acquired naturally and without apparent effort when children are exposed to it. Learning to read and write, on the other hand, is effortful and, for some children, very challenging. Literacy must be explicitly taught if it is to be reliably learned.

3. Working memory and cognitive load

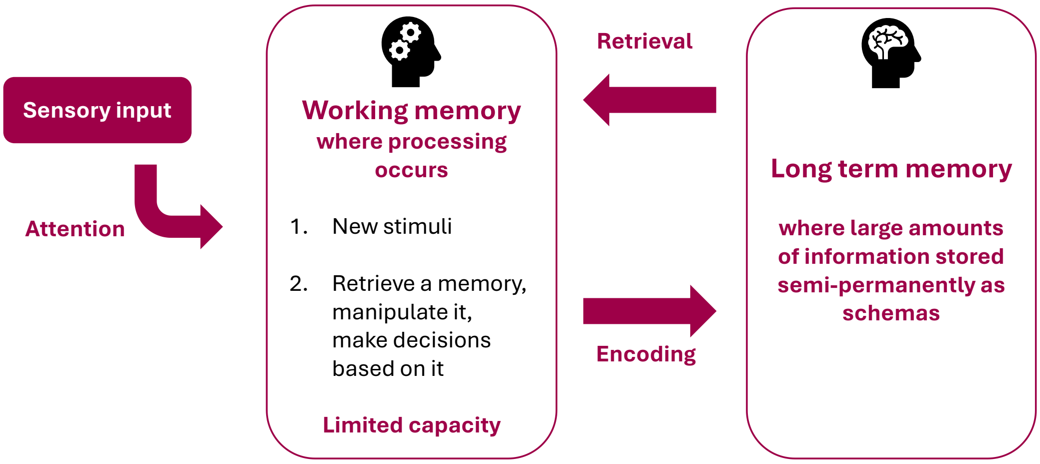
When a student first encounters new biologically secondary knowledge (see 2.5.2), it is stored in short-term *working memory.*[10] Working memory can be understood as the contents of consciousness. Whatever we are aware of at a given time is held in working memory.

As well as temporarily storing new knowledge, working memory holds knowledge that is recalled from long term memory. That enables us to reflect on it, to use it to solve problems, and to relate it to other knowledge. Working memory has a key role in integrating new knowledge with what we already know.

Working memory can hold only a small amount of new information at a time.[11] Moreover, information that is held there is usually forgotten within seconds unless it is rehearsed.[12,13] For example, if someone dictates their phone number, we must repeat it to ourselves until we can record it, or we will quickly forget it. The small capacity of working memory, and the brief duration for which information held is there, make working memory a 'bottleneck' for new learning.

Knowledge and skills must be transferred from working memory to long-term memory to be learned securely.[14] That requires deliberate practice.[15] Repetition is part of deliberate practice, but it is not enough on its own. Deliberate practice also requires motivation to learn and attentive engagement. Teachers help students to engage in deliberate practice when they find ways to make the repetition that is necessary for secure learning motivating and enjoyable. Teachers providing specific feedback on learning progress is also an important support for deliberate practice (see 4.0).

How memory works



All fluent use of knowledge and skilled performance is mediated by long term memory. There is no known limit to the amount of knowledge that can be stored in long-term memory. Knowledge securely stored in long-term memory is retained for years, decades, or a lifetime.

Consider the process of learning to drive. At first it is very challenging. There are many subtasks to coordinate – using the steering wheel, brake, and accelerator, as well as monitoring the road for curves, other traffic, pedestrians, and hazards. All those things must be managed by working memory. That is why beginning drivers must concentrate hard and are more likely to have accidents than experienced drivers.

With practice, the subtasks of driving are transferred to long-term memory. Coordinating those subtasks gets easier and requires less concentration. An experienced driver can safely have a conversation with a passenger unless road conditions are particularly hazardous.

3.1 Cognitive load

Because working memory can only hold a small amount of information at a time it is easily overloaded. The *cognitive load* associated with a task is determined by the amount of working memory capacity it occupies. Tasks that involve high cognitive load require a lot of concentration and effort. In contrast, tasks drawing on knowledge and skills securely stored in long-term memory are straightforward to perform and do not cause cognitive load.

Just about all the learning specified in the learning areas of the curriculum must be managed by working memory until it is encoded in long-term memory. That means students will often be working under high cognitive load while they are learning.

The selection of content for the curriculum (see 2.1.1) can contribute to managing students' cognitive load. Only the content that is relatively most important for students to learn at each phase of schooling should be selected, rather than overwhelming students with everything they could, in theory, learn. Even so, all curricula are premised on progression – moving students from one stage of learning to the next – with content gradually increasing in complexity. Teachers must therefore help students manage the cognitive load associated to enable them to progress effectively.[16]

Not all learning imposes the same cognitive load. The more elements that must be held in working memory at the same time, and the more relationships between those elements that must be considered, the greater the cognitive load will be.[17] Early literacy, mathematics, science, music and technology all involve frequent high-cognitive-load learning. Illustrations from early reading and mathematics learning are described below.

3.1.1 Early reading

For beginning readers, even decoding a single word can occupy a lot of working memory resources. A reader must segment words into graphemes[ii], store the graphemes in working memory while mapping them to phonemes, and then store the phonemes while they blend them to form the sound of the whole word.

As the grapheme-phoneme correspondences and the skills of segmenting and blending become more securely stored in long-term memory, the cognitive load associated with decoding reduces. That frees working memory resources to be used for comprehension and reflection. Once these decoding procedures are secure in long-term memory, they help students to fluently read words they have never seen in print before.[18]

3.1.2 Mathematics

Mathematics learning involves frequent episodes of high cognitive load at all stages of learning. In most mathematics learning, many elements and interrelations must be stored in working memory while carrying out procedures with them. That is why many students (and adults) find mathematics very challenging.

For example, consider a young student who is beginning to learn addition, trying to solve 5 + 4, using a counting-on strategy. The student must store both numbers, the interim solutions as they count on, and the number of remaining increments, in working memory.

When a student has stored basic addition facts in long term memory, there is no working memory load associated with solving 5 + 4. The solution is simply recalled from long-term memory. Having basic addition facts stored in long-term memory frees working memory to solve more complex problems using those facts.

In mathematics, the ability to learn a new procedure or concept almost always builds directly on previously learned procedures and concepts. For example, multiplication builds on addition. In mathematics it is especially important to transfer each stage of learning from working memory to long-term memory before building on it. Otherwise, students will have insufficient working memory resources available to process the new learning. That can result in them feeling that they are poor at mathematics. Some will then avoid engaging with the subject.

[ii] A grapheme is a letter or group of letters corresponding to a phoneme, or speech sound. Examples are /s/, /ch/ and /oo/.

3.2 Sources of cognitive load

Learning any new knowledge or skill involves two sources of cognitive load. They combine to give the total cognitive load students experience.

- **Intrinsic cognitive load**:[19] Cognitive load associated with the complexity of the knowledge or skill to be learned. It is primarily determined by the number of interacting elements that are new to the student.
- **Extraneous cognitive load**:[20] Cognitive load associated with the instructional methods and learning tasks that a teacher uses, and with distractions in the learning environment.

Working memory resources left available after accounting for intrinsic and extrinsic cognitive load can be deliberately devoted to connecting new knowledge with knowledge already stored in long-term memory. The extent to which these resources are *actually* devoted to this learning process is determined by the effort and motivation of the student.

3.3 Managing cognitive load

No new learning of biologically secondary knowledge can take place without imposing a cognitive load. Working memory, with its limited capacity, is always involved in learning new knowledge and skills. But when cognitive load is too great, it exceeds the capacity of working memory. That situation is called *cognitive overload*.

All students sometimes experience cognitive overload, but persistent cognitive overload impairs learning.[21] It can result in frustration, damage to self-efficacy and self-belief, and ultimately, disengagement. Teachers can help students to manage the cognitive load associated with learning, to avoid their working memories being overloaded too often. This can be done by:

- Ensuring that key learning is secure in a students' long-term memory before building on it with new learning. This reduces the intrinsic cognitive load associated with the new learning.
- Using instructional methods and learning tasks that do not cause higher cognitive load than necessary.[22] This reduces extraneous cognitive load.
- Ensuring an orderly and quiet classroom for high cognitive load learning. This also reduces extraneous cognitive load by reducing external distractions.

Reducing extraneous cognitive load increases the working memory resources available to be devoted to connecting the new learning with knowledge already stored in long-term memory.

The availability of working memory resources does not, however, guarantee that students will devote them to learning. That depends on motivational factors (see 5.2).

The amount of time spent engaged in high-cognitive load learning should be managed carefully, especially with young students and students with limited motivation or self-efficacy for learning. While it is important that students learn to persist with challenging learning, high cognitive load learning is fatiguing, and prolonged feelings of frustration can be demotivating. Taking a break and returning to a task fresh and with a clear mind can be an effective strategy. Learning is often more effective with briefer and more frequent engagement with high cognitive load activities than with longer but less frequent engagement.

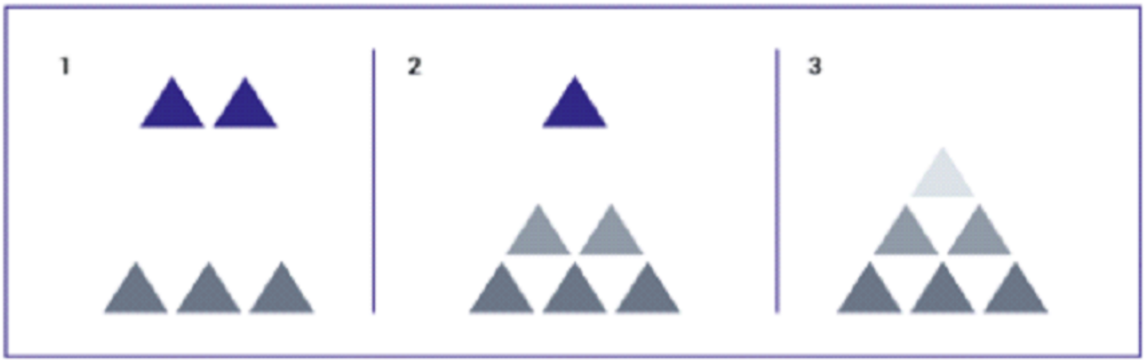
Russian educational psychologist Lev Vygotsky's concept of the 'zone of proximal development'[23] provides a helpful framework for managing cognitive load during learning. The zone of proximal development is the space between what a student can do independently, and what he or she cannot do even with guidance. Vygotsky died decades before cognitive psychologists first conducted research on working memory and cognitive load. Even so, in cognitive terms, the zone of proximal development can be conceptualised as material that has not yet been securely stored in long-term memory, but which imposes a manageable cognitive load with a teacher's guidance.

3.3.1 Managing intrinsic cognitive load: Schema formation in long-term memory

An important way in which teachers can help students manage intrinsic cognitive load is to sequence and pace instruction so that each stage of learning is transferred to long-term memory before proceeding to the next stage. That frees up working memory resources, which can then be used to engage with the next stage.[24] Knowledge from the previous stage can then be retrieved from long-term memory to support the new learning without additional cognitive load.

Coherent learning requires new knowledge and skills to be explicitly connected to what students already know and can do. Transferring new learning to long-term memory is assisted by connecting new knowledge to knowledge already stored in long-term memory. With deliberate practice, the new knowledge is integrated with knowledge and skills already stored in long-term memory. When new knowledge has been integrated in this way, the student has achieved cognitive automaticity with the that knowledge. That means the knowledge or skill can be accessed without cognitive effort. In fact, when an automatic cognitive process is cued by a stimulus in the environment, it cannot be suppressed. For example, a skilled reader cannot look at a written word and *not* read it.

Schemas structure knowledge in longterm memory



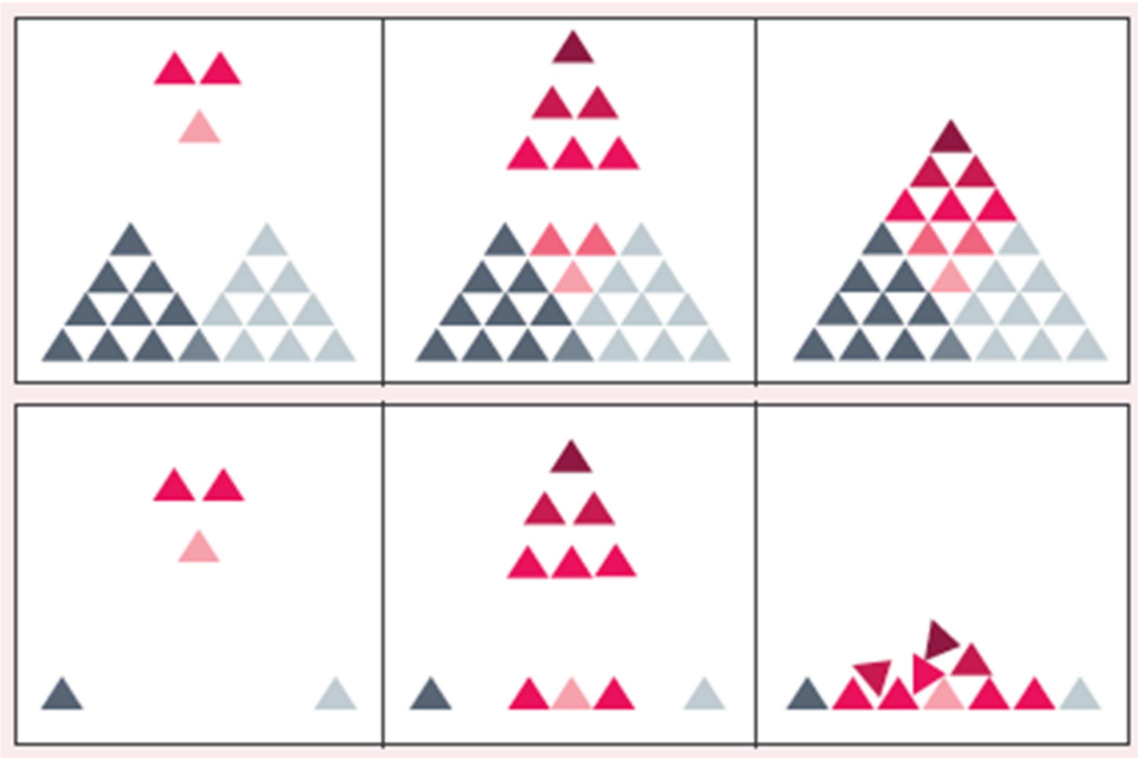
In long-term memory, related knowledge and skills are connected by cognitive structures called *schemas*.[25] For example, skilled violinists have schemas that coordinate the subskills of playing the violin – holding the bow correctly, precise fingering, reading music and so on. Similarly, mathematicians have schemas for solving algebraic problems that coordinate the various rules of algebra. Learning is the process of establishing and connecting schemas in long-term memory.

Very complex schema, securely stored in long-term memory, can be used by working memory without incurring cognitive load. Connected-up knowledge reduces cognitive load by enabling working memory to manage information more efficiently.

Schemas are arranged hierarchically. Very simple related elements of knowledge and skill are connected as schemas in long-term memory. With practice, those schemas also become connected to other, related, schemas into more complex schemas, and so on. In this way, very complex concepts and skills can be built up coherently in long-term memory and used in creative and innovative ways.

When teachers sequence instruction in a way that enables students to connect each stage to what they already know, they assist students to construct coherent schemas. Schemas must be established systematically so that learning is coherent and connected to what students already know.

Coherent schemas are arranged hierarchically



Schemas with missing or incorrect knowledge are disorganised

3.3.2 Reducing extraneous cognitive load

Teachers can reduce extraneous cognitive load by using instructional methods and learning tasks that impose as little cognitive load as possible. If a teacher selects learning activities that don’t themselves occupy too much working memory, more working memory capacity is left to process the new knowledge or skill. If instructional methods or learning tasks are more complex than they need to be, extraneous cognitive load is also higher than it needs to be. That reduces the working memory resources available to integrate new knowledge into schema in long term memory.

A student’s motivation and ability to concentrate on a task affects the cognitive load associated with that task. Distractions, such as noisy classrooms, increase students’ cognitive load. That is because distractions occupy working memory resources that could otherwise be used for learning. When students are engaged in learning that imposes a high cognitive load, it is important that distractions are kept to a minimum. Classroom should be as quiet and orderly as possible at those times.

Specific teaching strategies to reduce or manage extraneous cognitive load include:

1. **Worked examples**[26]

   A worked example is a clear illustration of a procedure for solving a particular kind of problem or carrying out a particular kind of process. Perhaps the most common usage of worked examples is in mathematics, but they are potentially useful in teaching any constrained procedure.

   Worked examples map out schemas for cognitive processes. They help to reduce extraneous cognitive load involved in learning a process by reducing the number of interacting elements that must be held in working memory. Because a worked example makes a procedure explicit, students don't need to hold the procedure itself in working memory. Instead, they can devote their cognitive resources to encoding the procedure in long term memory as they follow the worked example.

2. **Avoidance of splitting students' attention**[27]

   When students have to attend to two or more sources of information while they are engaged in a learning task, they must frequently switch their attentional focus from one source to another. That increases the extraneous cognitive load associated with performing the task.

   It is often possible to present a task in a way that reduces the need for students to split their attention. For example, if students must follow a diagram to perform the task, informative labels can be located near relevant elements of the diagram, rather than in a legend at a different spatial location. That eliminates the need for students to switch their attention between a legend and the elements of the diagram to which it refers.

3. **Avoidance of redundancy**[28]

   Conveying the same information in more one modality imposes a greater extraneous cognitive load than conveying the information from a single source. Such redundancy unnecessarily increases complexity for students with no increase in the information that is converyed.

   For example, when the same information is presented in both spoken and written form, the extraneous cognitive load is greater than it would have been if the same information has been communicated in just one modality. Similarly, the inclusion of labels on a diagram, if the information in the labels is self-evident in the diagram itself, unnecessarily increases extraneous cognitive load.

Using different modalities is not redundant if different, but related information is conveyed in each modality. In this case, using separately modalities can actually reduce intrinsic cognitive load. That is because working memory (see 3.0) has different sub-stores for language and visuospatial information. For example, a verbal explanation of a diagram that elaborates on the information in the diagram itself can aid comprehension of the diagram without redundancy.

4. Awareness of 'expertise reversal'[29]

The 'expertise reversal' effect is a special case of the redundancy effect, described above. Presenting the information same information from two sources simultaneously may be redundant for an expert, but not for a novice. For example, if a student is not a fluent reader, then reading text aloud while the student follows it visually can assist them to comprehend that text and may even improve their reading capability over time.[30] In this case, the two sources are not redundant, because the student cannot easily access the information through the visual modality (i.e., by reading it).

Whether or not a source of information is redundant depends, to some extent, on a student's level of proficiency in interpreting that source. For a student who is able to readily interpret both sources, extraneous cognitive load is increased by redundancy. For a student less proficient in interpreting the information from one source, extraneous cognitive load is not increased, and having the two sources available may support comprehension and learning. In this case, the two sources are not redundant.

3.4 Confusion

Confusion arises when new learning appears to conflict with what a student has already learned, or when critical connections between knowledge elements have not yet been made. Periods of confusion are inevitable in any complex learning. Some research suggests that working through confusion can lead to deeper learning.[31] But for that to occur, the confusion must be resolved.[32] If a student disengages due to confusion, they will not learn the concept that caused the confusion.

Confusion caused by something other than the concept itself – for example, the way in which a teacher is explaining, or extraneous elements of a learning task – is not productive. When confusion is caused by cognitive overload, a student is unable to work through it and may need assistance to manage the cognitive load associated with the learning.

3.5 Critical thinking and creativity

Critical thinking and creativity depend on connected-up knowledge – on coherent schema structures, in cognitive terms. No substantial critical thinking or creativity is possible without knowledge.

Critical thinking is the analysis, evaluation and synthesis of ideas, guided by reason, to reach conclusions. The more knowledge a student holds, the more material they have available to analyse, evaluate and synthesise. Without knowledge, students do not have the frames of reference necessary to analyse and evaluate ideas effectively.

Creativity is the production of something new, whether an idea, an artistic work, a technology or a skill. Sophisticated creativity is always grounded in what the creator already knows. It involves recombining existing knowledge in novel and innovative ways. It also involves an element of chance or randomness, and the knowledge to be able to select the best ideas for further development.[33]

A sports coach who invents a new strategy must know the rules of the sport, as well as enough about its tactics, to evaluate whether it is likely to be effective. The work of artists and musicians is rooted in their knowledge of cultural traditions. They must also have mastered enough technique – brushwork or skill with a musical instrument – to give effect to their ideas.

The process of learning itself can foster critical thinking and creativity. If new knowledge is taught in a way that encourages students to question and analyse it, it helps develop their critical thinking skills and to connect it with what they already know.

Being able to do this, however, depends on having sufficient working memory resources available. If students are experiencing high cognitive load, they will find it very challenging to question or analyse what they are learning. Interleaving periods of high-load deliberate practice with periods of reflection helps to manage cognitive load.

Both critical thinking and creativity vary across disciplines, although there are elements that are common across all disciplines. Critical thinking in science is different than critical thinking in history, even though both involve analysis and evaluation. Creativity in music is different than creativity in writing, even though both involve innovation.

When students are taught subjects based on disciplines in the context of a knowledge-rich curriculum, they do not only learn knowledge. They learn powerful ways of generating, analysing and evaluating ideas and creative works.

4. Formative assessment and feedback

If it is used well, formative assessment is one of the most powerful tools at teachers' disposal.[34] It is a highly effective way of managing the intrinsic cognitive load associated with learning, because it helps students integrate new learning into their existing cognitive schemas in long term memory (See 3.3.1). Effective formative assessment has three essential components:

- The teacher and student must have clear understanding of the learning goal that the student is working towards, and of the key steps to attaining that goal.
- The teacher must be able to assess where a student is on the pathway towards that goal.
- The teacher must be able to provide feedback that assists the student to move towards the goal.

4.2 Learning goals

Learning goals should be challenging but achievable. Goals that are too easy to attain are not motivating and the student will not learn much. Goals that are unattainable set students up to fail. Vygotsky's concept of the 'zone of proximal development'[35] is useful in setting learning goals: A learning goal in a student's zone of proximal development is one that is too challenging for the student to master by themselves, but which is attainable with a teacher's instruction and guidance.

Goals should be selected with regard to students' motivation and self-efficacy. More motivated and independent students can be given more challenging goals. Students who lack motivation or confidence benefit from more modest goals. Attainable but challenging goals, with formative feedback to help students attain them, are highly motivating.[36]

Learning goals should be specific and measurable, so that students and teachers understand when they have been met. Specific goals also help in giving well targeted feedback.

4.3 Assessment for formative purposes

Formative assessment is any activity that provides teachers with information about the current state of a student's learning used to inform specific feedback. It can be based on structured tasks like tests and written work. It can also be as simple as everyday observations and interactions between teachers and students. One of the most effective approaches to formative assessment is to have brief but frequent and focussed conversations with students, seamlessly incorporated into classroom instruction.[37]

The goal of formative assessment is to gather information about where a student is in relation to a learning goal. When the teacher and student both understand the learning goal, that information can then be used to shape effective feedback.

4.4 Feedback

Feedback can come from many sources, including books, peers and experience. The most effective feedback comes from skilled and knowledgeable teachers.

Effective feedback can help students to:

- Correct errors
- Identify and fill gaps in their knowledge and skill
- Adopt more effective learning strategies
- Self-regulate their learning activities[38]

To be effective, feedback must convey specific information about how to close the gap between what a student has already learned and their current learning goal. Grades, tests scores and praise do not constitute effective feedback and may even harm students' learning motivation.[39] Feedback is most effective when it connects to what a student already knows or can do. If it does not, the student cannot use it and may find it frustrating and demotivating.[40]

3.4.1 Feedback and cognitive load

Feedback should be provided with consideration of the extraneous cognitive load it creates (see 3.3). The cognitive benefit of the feedback must outweigh the cost of processing it. In cognitive terms, feedback that connects to what students already know can reduce intrinsic cognitive load by assisting them in forming coherent schema in long-term memory (see 3.3.1). Specific feedback without unnecessary or distracting elements reduces intrinsic load and minimises additional extraneous load.

3.4.2 Timing of feedback

In general, feedback is most effective when it is immediate. That is especially the case with feedback that corrects specific errors.[41] In high-cognitive-load learning, some delay between performance of a task and feedback may be beneficial.[42] That is likely to be because the extraneous cognitive load of immediate feedback adds to the intrinsic load of performing the task, which may result in cognitive overload.

5. Learning is emotional, social and cognitive

Human learning processes involve a complex mix of emotional, social, cognitive factors. In purely cognitive terms, learning biologically secondary knowledge can be conceptualised as the process of establishing knowledge and skills in long-term memory. Even so, neuropsychological research shows intimate links between emotions, learning and thought. [43] The cognitive processes involved in learning are strongly influenced by social and emotional factors.

5.1 Social influences on learning

Human beings are social animals. We need to feel a sense of belonging in social groups and communities to thrive. Schools are a major component of students' social lives. Students who have a sense of belonging in the schools and classrooms are less likely to engage in antisocial behaviour[44] and truancy[45]. Belonging has also been shown to be positively associated with educational achievement.[46,47]

The causal direction of these relationships is unclear in the research literature because they are measured using correlations.[48] For example, it is not clear whether students tend to achieve more in their learning if the feel a sense of belonging, or if they tend to feel a sense of belonging if they are achieving well in their learning.

In many cases, relationships between sense of belonging at school and positive engagement and achievement are likely to run in both directions. Schools fostering a sense of belonging is a good starting point for leveraging students' positive engagement with, and success in, their learning.

Strong school communities, in which teachers support students and students support one another is strongly associated with students' sense of belonging. Students feeling that they have positive relationships with their teachers and trust them with personal problems are likely also to feel a sense of belonging at school.[49] School leaders can encourage this by setting up pastoral support systems in their schools. Involving families in school life is another way to foster a strong sense of belonging in students.

5.2 Motivation, self-regulation and educational achievement

The relationship between motivation, self-regulation and learning is complex and has sometimes been oversimplified. A good example of oversimplification is the influence of mindset theory[50] in education.

Some researchers have claimed that holding a growth mindset – the belief that intelligence and abilities can be improved – motivates students to achieve in education.[51] Growth mindset is contrasted with fixed mindset – the belief that intelligence and ability cannot be changed.

According to mindset theory, students with growth mindsets adopt motivations and self-regulation strategies that result in more effective learning than students with fixed mindsets. This has led to interventions to move students from a fixed mindset to a growth mindset to improving their learning.

Unfortunately, the evidence for growth mindset interventions actually improving educational achievement is very weak.[52, 53] Encouraging students to adopt growth mindsets is, on its own, unlikely to improve their learning. Even so, although mindset does not seem to affect educational achievement, there is nonetheless a strong relationship between motivation, self-regulation and learning.

Self-regulation involves a variety of metacognitive strategies, including the ability to concentrate, to set and monitor progress towards goals, and to manage anxiety. Motivation and the ability to self-regulate have a reciprocal relationship: Motivation is positively influenced by self-regulation behaviour, and self-regulation is improved by motivation to learn.[54]

The reciprocal relationship between self-regulation and motivation, and the positive effect of both on learning can be understood in terms of cognitive load theory (see 3.1). Working memory resources left available after accounting for intrinsic and extrinsic cognitive load can be allocated to integrating new knowledge and skills into existing schema in long-term memory. However, students must be self-regulated and motivated to do this.

Unlike intrinsic cognitive load and extraneous cognitive load, germane cognitive load is under a student's control. The allocation of working memory resources to germane cognitive load is effortful and draws strongly on self-regulation. It requires concentration, management of frustration, confusion (see 3.4) and anxiety, and persistence with high-cognitive-load learning. Motivated students, and students with strong self-regulation strategies, are more likely to engage in sustained allocation of working memory resources to deep learning than those with weak motivation or poor self-regulation.

Teachers can assist students to engage in positive self-regulation by helping them to:

- develop strategies to concentrate
- set manageable learning goals and monitor their progress towards them, including providing specific feedback (see 4.4)
- develop strategies to manage confusion, anxiety and stress in high-cognitive load learning
- persist with high-cognitive load learning

Making progress in learning is itself motivational. When students know that they are making progress, it strengthens their willingness to engage in high-cognitive load learning. That engagement, in turn, strengthens the self-regulation strategies make high-cognitive-load learning easier.

6. Situating the key competencies in the science of learning

The current New Zealand curriculum[iii] specifies five key competencies:

1. Thinking
2. Relating to others
3. Using language, symbols, and texts
4. Managing self
5. Participating and contributing

Many of the key competencies are examples of biologically primary knowledge – knowledge that human beings have evolved to learn naturally and with little effort (see 2.5.1). Even so, schools and teachers important in roles in creating environments in which students will acquire biologically primary knowledge.

Some students also benefit from explicit teaching of biologically primary knowledge, especially those who do not exposed to strong models of oral language and social skills in their lives outside of school.

Schools assist children to learn positive ways of relating to others when teachers model positive relational behaviour. Rules of behaviour that require courteous interactions between peers also help students develop adaptive social skills.

6.1 Thinking

Thinking is the biologically primary skill of using knowledge to solve problems. Even very young children can think. However, the more knowledge we have, the better is our thinking.

Learning the knowledge specified in the learning areas of the curriculum helps students develop their thinking skills. While thinking itself does not have to be explicitly taught, the knowledge that best assists its development does.

Advanced thinking skills, like critical and creative thinking cannot be acquired without knowledge. Disciplinary knowledge (see 2.2) – including both the content knowledge and the disciplinary modes of inquiry of specified in the curriculum learning areas – is highly effective for developing critical and creative thinking. The modes of inquiry, in particular, have been

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[iii] We understand the Ministry is considering a revised classification of competencies – we will modify the paper accordingly once this is decided.

developed and refined over time – in some cases, millennia – by communities of scholars, to produce and test new knowledge. That makes them especially powerful in developing students' ability to think critically and creatively. Disciplinary learning frequently imposes a high cognitive load. That means that disciplinary knowledge must be taught explicitly if students are to learn it reliably.

6.2 Using language, symbols, and texts

Oral language is a biologically primary skill. From an educational perspective, oral language is critically important.[55] Students who start school with strong oral language skills can fully benefit from learning interactions with teachers and peers.[56] They are set up to learn to use the symbols of written language to read and write, and to engage with text for learning and enjoyment.[57] They have a head-start in education that flows through to employment and many other important life activities.

Providing a rich oral language environment at school is the most effective way to support the development of students' oral language. When teachers use language that is a little more advanced than that which students use themselves, students are exposed to new vocabulary. Reading aloud to students can also help to build their oral vocabularies, as well as feed a love of literature.

Although oral language is a biologically primary skills, explicit teaching is sometimes required to improve oral language skills for children who lack those skills when they start school.[58] Some children need opportunities, and to be supported to talk, to learn to take turns in conversation, and to acquire vocabulary. Many children need to be taught how to engage in to-and-fro dialogue and discussion, and most, how to speak publicly (oratory).

Older students need to be explicitly taught oral language skills that relate to academic and disciplinary conventions. Like the disciplinary modes of inquiry (see 6.1), these conventions have been developed and refined by communities of scholars to provide powerful means of testing, contesting, and refining knowledge claims.

Unlike most oral language, the ability to use symbols and to engage with written texts is biologically secondary knowledge (see 2.5.2). The ability to use and interpret symbols is essential in learning to read and write, mathematics and reading music. Symbols are also used in chemical equations and other aspects of science and technology. Because the ability to use symbols is biologically secondary, these skills must be explicitly taught to be learned reliably. Teaching must be structured and sequenced to manage the cognitive load involved in integrating these skills in long-term memory (see 3.3.1).

6.3 Managing self

The competency of *managing self* encompasses motivation and the self-regulation needed to make progress in high-cognitive load learning (see 5.2). There is a complex relationship between motivation, self-regulation and learning. They can form either a positive or negative cycle.

Students who are motivated to learn will persist more with challenging learning. If they are supported to develop self-regulation, they will progress in their learning. That, in turn, is motivational and helps to further develop self-regulation. On the other hand, students who struggle to make progress may become demotivated and dysregulated. They may ultimately disengage from education.

Teachers can help students develop a positive cycle of motivation, self-regulation and learning when they have strong relationships with their students and use teaching methods that manage cognitive load (see 3.3).

Managing self also encompasses important qualities like punctuality, personal reliability, taking responsibility and fulfilling promises. Schools help students develop these qualities by setting them as expectations for conduct and holding students accountable. Teachers help students develop these qualities by modelling them in their own conduct.

6.4 Relating to others

Relating to others requires social skills. Like thinking skills, social skills are biologically primary. They are acquired mainly through interaction rather than through explicit teaching. Social skills include empathy, courtesy, generosity, assertiveness, and being able to perceive how others are feeling through their facial expressions and body language. Oral language (see 6.2) also contributes to students' ability to relate to others. This includes not only the ability to comprehend and express ideas using language, but also understanding and using the conventions of conversation, including active listening and taking turns in speaking.

The quality of social interactions at school strongly influences the ways in which children learn to relate to others. For example, children are assisted to acquire courteous patterns of behaviour if others behave with courtesy towards them. They are also likely to learn negative ways of relating to others, like bullying behaviour, if they are victims of such behaviour themselves.

6.5 Participating and contributing

Participating and contributing is also a biologically primary social competency. It relates to being active in community. It encompasses reciprocity, taking personal responsibility for collective wellbeing, and personal reliability. Schools and teachers assist students to acquire this competency by setting strong expectations for these qualities and holding students and themselves accountable for meeting those expectations.

The quality of a school community influences students' acquisition of this competency. Students who have a strong sense of belonging in their school communities are assisted in learning to participate and contribute (see Section 5.1).

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