they happened to attend. In the grand scheme of things, for those people in those roles, it doesn't really matter.

An additional complication is the way these two characters integrate their knowledge of gravitational theory with other theories. A sniper also needs a deep knowledge of the effect of the wind on flight paths, camouflage, military tactics and anatomy. An engineer predicting the motion of asteroids does not. As such, despite them both using broadly the same theories, the applications will vary widely, as will their understanding of the evidence base for that theory.

In sum, we have three levels of knowledge:

Level 1: empirical observations about the world.

Level 2: theory to explain those observations.

Level 3: translation into concrete application.

This is a heavy simplification. The necessary components and logic of the 'scientific method' are hotly contested to this day. For example, the functions of prediction, peer review, falsification and validation have here been entirely glossed over. To an extent, this chapter follows the philosophy first raised with our sniper and our engineer: we don't all need to understand all the details to have a functioning and useful knowledge (Popper, 1959).

Until now, we have discussed one field of science: physics. There are of course other fields, and our particular interest in this book is cognitive science. Cognitive science investigates our three levels as they apply to the realm of cognition: **thinking**, **learning** and **remembering**. We take an observation about learning – some piece of empirical evidence – and we think of a theory to explain why it happened. We then run an experiment to gather more evidence and test whether the theory is correct, or whether we will have to return to the drawing board.

This more or less covers questions 1 and 2: what is happening and why is it happening? When it comes to question 3, we move away from the clean and controlled conditions of the cognitive scientist's laboratory and into the messy chaos of the classroom. The baton is passed from scientist to teacher, and questions of action and application become apparent.

As above, not every teacher needs to know every aspect of every theory generated by cognitive science. We certainly do not need to be familiar with the intricacies of particular pieces of evidence that have been generated and verified. That isn't to say that *nobody* needs to know this, rather that *these people* don't need to know this. Broadly, teachers need to know enough to be able to make effective

decisions and predictions in the classroom (Willingham, 2019). That isn't to say that they *shouldn't* know more, rather that they *don't necessarily need to.*

An example: there are many different types of information that can be processed by the human mind, such as visual information like a picture, auditory information like a noise, or verbal information like words and language. In describing how these different types of information are processed and stored, cognitive scientists use terms like logogens, coding, imagens, modal-specificity, dual-channel processing, visual-spatial imagens, sensory-motor experiences, motor imagens, representational connections, referential connections and associative structures. These terms and processes are all supported by evidence from a range of sources, and are part of the language used by cognitive scientists to describe information processing.

Without a doubt, understanding these terms is not beyond the average teacher. Given time, effort and guidance, teachers could comprehend and assimilate these ideas. Whether it is worth that time is an entirely different question: will this understanding make enough of a difference in the classroom to justify the time investment?

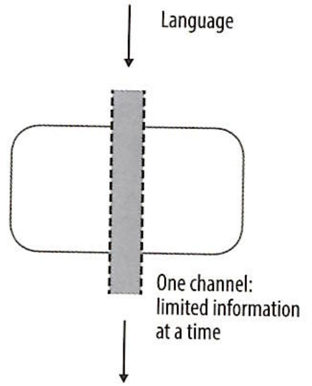
In our particular case of information processing, it is my opinion that a simplified summary of levels 1 and 2 will give us enough material on which to make concrete classroom decisions. As above, this is not to say that is all there is, rather that this is probably sufficient for most teachers most of the time.

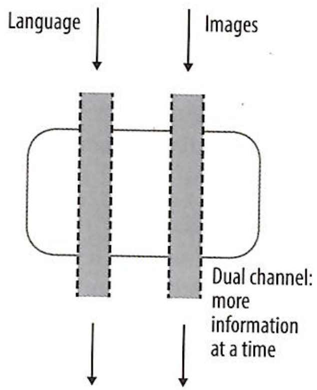
Level 1: empirical evidence regarding information processing

The scientists Richard Mayer and Richard Anderson presented study participants with different types of information about how a bike pump works, then asked them questions to test their understanding (Mayer & Anderson, 1991). Broadly, the information was in two types: word-based bike pump explanations, and a series of images focused on the same explanation. Mayer and Anderson tested a number of combinations (words by themselves, images by themselves, words then pictures, words with pictures) and found that participants who were presented with the words and the pictures simultaneously understood the material far better than any other combination. This empirical observation accorded with previously published research into the use of words and images, and was further confirmed by later research. This observation is often termed as **multimedia learning**: using different media (i.e. words and pictures) results in better learning.

Level 2: theorising

Findings like this are potentially explained by the following: whenever we have to take in new information, it passes through our **working memory**. Our working memory is limited and can only hold a small amount of information at any one time (as discussed in chapter 1). Information passes through the working memory in 'channels', which are narrow and constricted. Although we cannot widen any particular channel, it could be the case that we can add more channels, thereby increasing the amount of information that can pass through at any given point. Perhaps there is one channel for visual information, through which pictures pass. Perhaps there is a different, separate channel for language-based information that can be utilised at the same time.





If we can pass information through both channels at once, we have **effectively increased the capacity of working memory**, and to an extent circumvented its restrictions. This theory – that there are two channels – is often termed **dual coding theory** (DCT). In the words of the educational psychologist Paul A. Kirschner:

> *According to dual coding theory, if the same information is properly offered to you in two different ways, it enables you to access more working memory capacity. This means that you can benefit from access to both visual and verbal memory capacity.* (Kirschner, 2019)

In sum, when information is presented to a student in these two ways, they 'dual code' it. It enters their minds via these two channels.[1]

1 Note that this is a process that happens in the learner's head, not something the teacher does. Teachers cannot 'dual code' by showing images or the like – the dual coding happens entirely elsewhere.

Level 3: application

As such, we have some strong empirical findings and a theory we can use to harness those findings. If students learn better when material is presented verbally and pictorially then we can establish classroom routes to forming concrete applications. Some of these applications will be straightforward, but others will need us to consider other theories as well.[2]

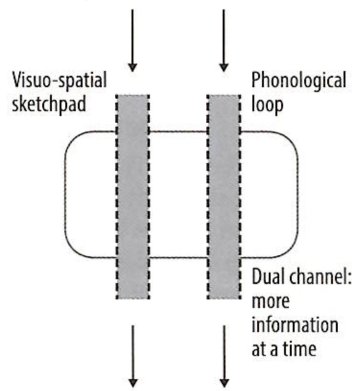
Where possible, use diagrams

On page 42 you saw a diagram showing the two channels. This diagram enabled you to assimilate the new information using both your language channel and your image channel, and helped you to better understand the material. This is the basic and most fundamental principle in this chapter.

Segment

There are some terms we are yet to use when it comes to a more complete understanding of DCT. For example, rather than use the terms 'image-based' and 'language-based', as we have done until now, cognitive scientists tend to describe the two channels as:

- **The phonological loop**: a channel that deals with any kind of language. This can be spoken or written.
- **The visuo-spatial sketchpad**: a channel that deals with anything you can see that doesn't have language associated with it, so a plain picture with no written words or nobody narrating it. We can add this to our diagram…



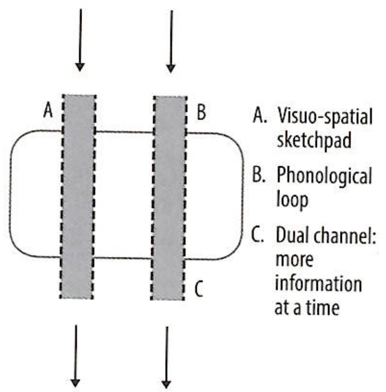
2 Many of these applications are raised, quantified and analysed in a useful summary by Richard Mayer: https://my.chartered.college/impact_article/how-multimedia-can-improve-learning-and-instruction

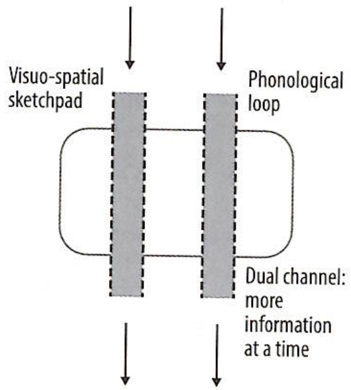
We could have added these labels right at the start, but at that point you were already grappling with so much information that adding two new technical terms could potentially have overloaded your working memory. True, we were increasing the capacity through use of the diagram, but that doesn't make it unlimited. This principle is summarised by the educational psychologist Barak Rosenshine as:

> *...more effective teachers do not overwhelm their students by presenting too much new material at once. Rather, these teachers only present small amounts of new material at any time, and then assist the students as they practice this material. Only after the students have mastered the first step do teachers proceed to the next step.* (Rosenshine, 2012)

Keep things together

Which diagram is better?



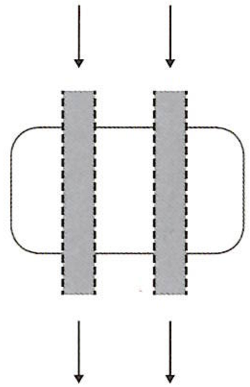


Evidence suggests that the diagram on the right is more effective for learning (Johnson & Mayer, 2012). This is potentially because matching up the letters (as you have to do for the diagram on the left) requires a small amount of cognitive effort that can no longer be dedicated to processing the relevant information. Wherever possible, avoid this by integrating your labels with your diagrams.

Eliminate redundancies

If I were not writing in a book, but lecturing in a hall, I would be conveying phonological information directly to your ears and eyes. I would use a diagram

to explain DCT, but I would not use the diagram I have already used. Instead, I would use the diagram below:

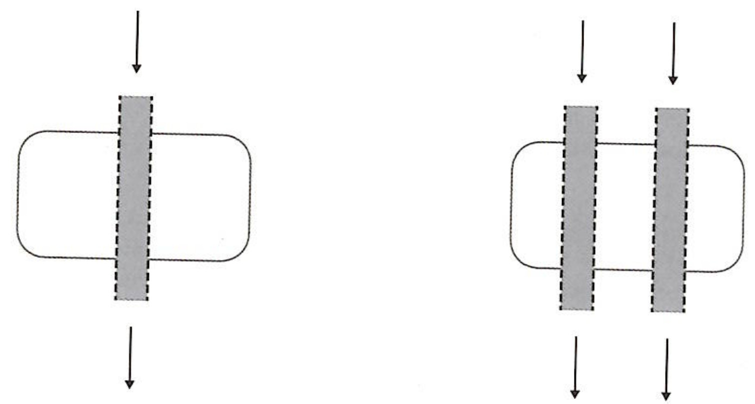


This is because I do not need you to be able to read the phonological descriptions *and* hear them. It's the same information, and saying it to you and having you read it at the same time does not utilise any additional channel beyond your phonological loop. At best, doing both does not add anything to your understanding or ability to process. At worst, it actively takes away, as you try to filter out one source of information while focusing on the other.

Reading out text that is already written down somewhere is redundant: by definition, it is not necessary and can be harmful to your explanation and to your students' understanding. Once you have finished your explanation, you might want to present a fully labelled diagram as a summary, but there is little point in doing this as your explanation proceeds.

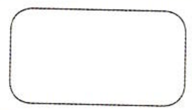
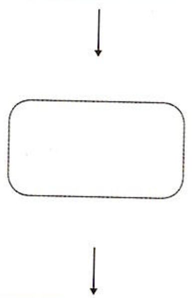
Manage and direct attention

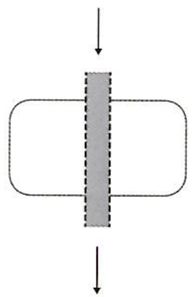
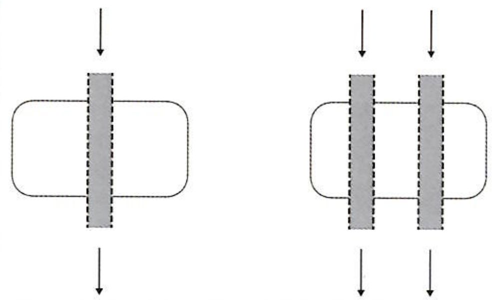
The cognitive scientist Daniel Willingham argues that 'memory is the residue of thought': students will not learn what they do not think about, and they will not think about what they are not paying attention to (Willingham, 2008). It is therefore imperative that when using a diagram, teachers clearly direct students' attention to the parts of it they are talking about. For example, if you are using the diagram on the next page...



…you will want to point at the various parts and ask students to attend to them as you are discussing them: 'So, over here [point at diagram on left] we only have one channel, but over here [point at diagram on right] we have two channels.' Alternatively, you could use different colours or highlighters to draw attention to the various parts as you explain them.

However, even with gesturing or highlighting like this, there is still the chance that students will be looking elsewhere. All parts of the diagram are potential sites for distraction: while you are talking about the one channel, students could be looking at the dual channels, and vice versa. To better manage this, it is often more effective to start a diagram from scratch and slowly build it up, thus controlling the flow of information and students' attention. For example:

	This is your working memory.
	Information needs to pass through your working memory.

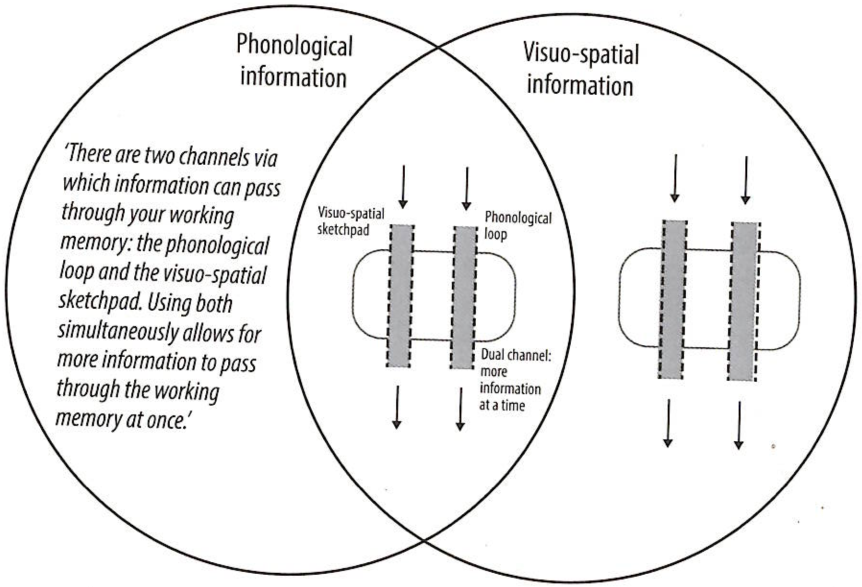
	If you have one type of information then there is only one small channel for the information to flow through.
	However, if you have two types of information, there are two channels available for the information to flow through.

Organise information

Most of the information we teach students is complex and interrelated. A visual representation of those interrelations can aid students' understanding and assimilation of that information. For example:

Type of knowledge	Level 1: empirical evidence	Level 2: theory	Level 3: application
Gravity	Things fall down.	Theory of gravitational attraction.	NASA engineer plotting a course for a rocket.
Images and explanations	When images and verbal explanations are presented simultaneously, learning is improved.	Dual coding theory.	Teachers building explanations.

Often, simpler is better. Lists, tables and Venn diagrams are effective and not overly complicated, and should be used unless the alternative is clearly superior.



Recently, there has been a trend to create graphics that do not appear to be significantly superior to a simple list, table or diagram. For example, road maps showing different subjects can be hard to follow and do not show the connections between topics. On the other hand, attempting to show all the connections between topics can rapidly become confusing and unhelpful. A balance must be struck and a list or a table often does the job.

Confusing aesthetics with learning

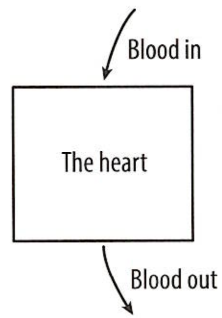
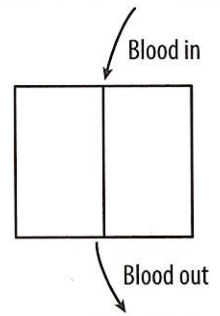
Another recent trend surrounds the use of principles from contemporary artistic design in preparation of educational materials. There is often a useful overlap between the aesthetic and the educational, but this is not always the case. The recent proliferation of icons on educational materials does not appear to be supported by any clear research or systematic theory of use, and is therefore at best a waste of time, and at worst a site for distraction or redundancy. The science teacher Pritesh Raichura suggests querying the use of items like:

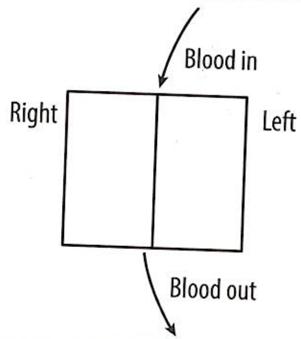
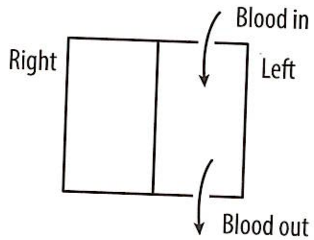
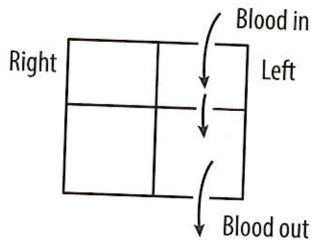
- *Icons to represent headings (dollar notes to represent economic arguments).*
- *A series of pictures organised into a complex structure that a list could serve equally well instead (literal roadmaps of the curriculum, I'm looking at you).*

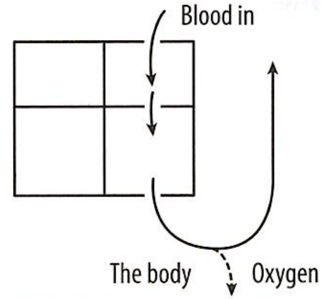
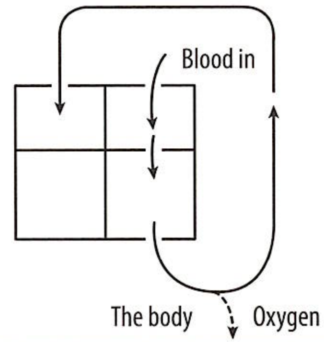
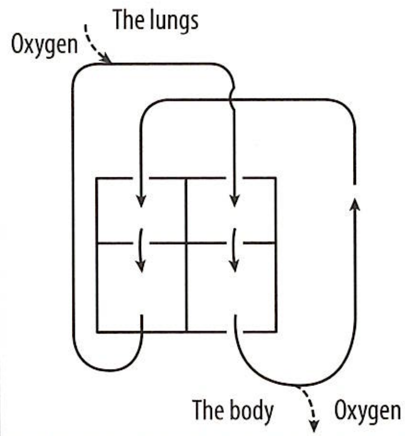
- *Images that show something that can be so easily imagined are rather pointless (stack of books next to a text about reading).*
- *Pictures for comic effect.* (Raichura, 2020)

Blank canvassing

In a bid to harness DCT, I ordinarily recommend that teachers take a 'blank canvas' approach to their explanations, which involves starting each diagram from scratch and narrating as you go. Here is a science example (Boxer, 2021).

For many years, doctors and scientists didn't really know much about blood and the heart. They had ideas that seem strange to us about how the lungs were to do with cooling down blood, that the heart was what kept us warm and things like that. A scientist called William Harvey found out that actually the heart is a pump for blood, pushing blood round the body through the blood vessels. It's a bit complicated how this works in humans, so I'm going to make it as simple as possible.	
We can think of the heart as like a big box. Blood comes into the box at the top, and out of the box at the bottom.	
When we look a bit closer, we see that the heart is actually split into two halves, so let's draw a line down the middle.	

Now I'm just going to do the same diagram on the mini-whiteboard, and hold it to my chest in the same place that my heart is found [hold it face out on your chest, so students will be able to understand the left/right half].	
The half over here [points to left side] is on my left, so we call it the left side of the heart, and the half over here [points to right side] is on my right, so we call it the right side of the heart.	
Let's start with the left side of the heart. Blood comes in at the top, and leaves at the bottom.	
But you remember how we started with one box, then we made it a bit like two boxes? There's actually another box in there that looks like this: Each box is like a little pump, and there's a space for blood to get through here, too.	

So blood comes in at the top, gets pushed through the hole here into the bottom pit, and then gets pushed out again to the body. As it passes through the body, it gives away its oxygen, like this:	
So if it's lost oxygen, it now needs to go pick some more up. Where does that happen? Good, the lungs. Unfortunately, it can't go straight there. The blood by this point is moving really slowly, so it needs a bit of an extra push to be able to get all the way to the lungs. So it actually goes back to the heart first, but goes to the other side.	
The same thing happens here. It goes in at the top, gets pushed down to the bottom, then gets pushed out again up to the lungs. At the lungs, it picks up some oxygen, comes back down to the heart ready for another big push, and then heads out to the body again.	

This is not the end of the story, and we would then add labels for the various blood vessels, as well as showing students photographs or more realistic diagrams to strengthen their comprehension of the heart's structure and function. We might also use a table to summarise:

Blood vessel	Goes from the...	To the...	Oxygenated or deoxygenated?
Aorta	Left ventricle	Body	Oxygenated
Vena cava	Body	Right atrium	Deoxygenated
Pulmonary artery	Right ventricle	Lungs	Deoxygenated
Pulmonary vein	Lungs	Left atrium	Oxygenated

Summary

DCT is a powerful theory that can drastically improve the quality of your explanations and your students' understanding of them. Its evidence base is robust, but also complex and broad. A number of principles have emerged from DCT and from other theories in cognitive science, and these principles should play a crucial role in the decisions made by teachers, in order to secure and consolidate student knowledge and understanding as it grows and coheres over time.

About the author

Adam Boxer is a science teacher and lead practitioner at a school in North London. He is also education director at Carousel Learning, an innovative online platform aiming to improve student outcomes and reduce teacher workload. Adam delivers CPD nationally and internationally. He is the author of *Teaching Secondary Science: a complete guide* (2021) and the editor of *The researchED Guide to Explicit and Direct Instruction* (2019).

Scan the QR code to watch a researchED video of Adam talking about dual coding (youtu.be/16SBht2iF_k).

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