Cracking Science

Build a world-class curriculum

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mastery science

Contents

Introduction

Who the book is for

Science educators have a pretty big challenge. We have to communicate a difficult subject to students who may not be eager to learn and we're often saddled with a curriculum that is so focussed on exam preparation, it gets in the way of achieving what we really want: to turn students into scientific thinkers and inspire some to go on to become scientists and engineers.

The belief that a curriculum that thunders through the specification is the best form of exam preparation is widespread, and wrong. It is based on a faulty assumption that learning is like a straight line between two points. In fact, the GCSE examinations tests not only what students know but also their depth of understanding, and whether they can use the knowledge to apply and analyse. The world of learning is multi-dimensional, not flat. And the shortest distance along a curve like the globe is not a straight line, but a geodesic. Many educators, including the current Ofsted Chief Inspector Amanda Spielman, maintain that the best form of exam preparation is a curriculum aimed at understanding, application and analysis. That's what this book shows you how to create.

If you're improving your school's curriculum by rewriting schemes of work, or starting a programme from scratch, this book offers a framework for making sound decisions: from organising units into a developmental sequence, to writing objectives at the right level of demand, to designing assessments that reveal understanding. If you don't currently have the power to change your curriculum, the book will give you arguments to persuade those who do. If yours is an advisory role, such as curriculum developer or trainer, the principles described here can give you a stronger rationale for your practice.

Why I wrote this book

I experienced school science as a dull and irrelevant body of knowledge to memorise. Despite all the research and billions thrown at STEM education since, students' experience doesn't seem to have changed much. What turned me on to science was having to teach it. I couldn't bear the thought of inflicting more punishment on the next generation, so I looked around for inspiration. Bookshops were full of stories of scientists discovering the mysteries of space, time, and evolution. And TV programmes like Horizon followed scientists pursuing their passions and proving their thories. Popular science was thrilling. Why did school science have to be so unpopular?

It's ironic that although enquiry is a big part of the curriculum, students don't science by actually doing it. Instead they generally just learn about what scientists discovered. If only science were a bit more like the real thing. Students would not only be more motivated, they would likely get more marks at GCSE, which increasingly rewards enquiry.

Making science more authentic has been a driving force in my work. At the beginning, my efforts were based on intuition and teaching experience. But lacking the rigour of research, they were a bit hit and miss. So I made a commitment to find evidence or theory to back up every decision I had to made in curriculum design. And this, more than anything else, has led to the curriculum framework described in the book.

Research into practice

Designing a curriculum is like engineering. Mechanical engineers need scientific principles to build structures that stand up. Curriculum engineers need principles from cognitive science to design learning that works. The problem is there are no over-arching theories akin to Newton's laws that tell us exactly what to do. Learning is too multi-faceted for and silver bullets. Yet that is no reason to discount research. Researchers have come up with hundreds of useful theoretical ideas over the last 60 years that tell us a lot about students' minds. Most of the findings are unknown to teachers. In this book I have pieced the findings together into a kind of patchwork theory which Mastery Science has used to design its curriculum framework, called Blueprint. The work has been supported by the Awarding Body, AQA and the Institution for Mechanical Engineers.

Solving curriculum problems

The original idea for Blueprint emerged from working with teachers. Whenever I asked colleagues what were their main curriculum problems, they would come up with a list like the one below. Which apply to your situation? All of the problems seemed solvable with better curriculum design. But it took several years for the mastery curriculum framework to take shape.

- Useless knowledge: Why can't students use their knowledge in unfamiliar situations?
- Lack of skills: How do I make the time for the skills students need?
- Conceptual demand: If students can't cope with the concepts, how can they Apply?
- Everything's forgotten: Students don't retain things. I have to re-teach everything.
- Lack of engagement: How do I engage students enough to learn the hard parts?
- Differentiation: How do I tailor learning, particularly for those who struggle?

For this book, I decide to maintain the emphasis on how the mastery curriculum solves the problems teachers identified. So I have organised the content so that there is a chapter about each, followed by on that showing how the curriculum framework solves it. As Blueprint is still a work in progress, this book is likely to evolve too. If you have thoughts on how to improve it, please get in touch.

Tony Sherborne, Mastery Science

1. Problem: Useless knowledge

Carrotgate

It's 2018, the first year that the new science GCSE is examined, and candidates are flummoxed by a question about the mass of a carrot. Later that day, Twitter buzzes with students' complaints that they had not been taught about it. Of course they had - they had even done the experiment. before The only difference was, that in asking a question about osmosis, examiners had substituted the familiar potato with a different vegetable. I mean, how unfair.

'Carrotgate', or students inability to apply what they learn, is a perennial problem. The physicist Richard Feynman referred to it as 'fragile knowledge'. As soon as you change the situation from the one students were taught about, they come unstuck.

When exams were merely testing memorisation, this was not such a problem. Now GCSE is more demanding, with 40% of the marks for applying knowledge. 20% of the marks require even more mand is even more knowledge trasnfer as students have to analysing new information. Here is an example (Figure 1). It involves combining concepts, evaluation and communication skills.

Carrotgate is only going to get worse. Governments are likely to respond to increasing competitiveness for jobs (and the

It is claimed that burning wood chip is a renewable, carbon-neutral method of obtaining energy.

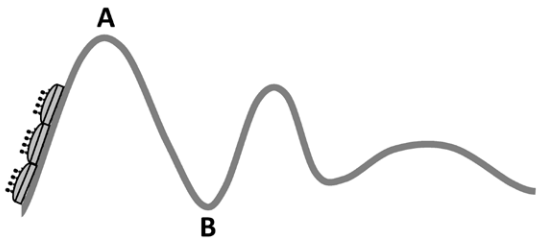
Read the statements about burning wood chips.

- It is estimated that the UK will burn 15-25 million tonnes of wood chip a year by 2017.
- Most of the wood chip burned in the UK comes from ancient hardwood forests in the USA, which have taken centuries to grow and are biodiverse.
- The wood chip is transported to the UK in bulk carrying ships, which burn fuel oil.
- Demand for wood chip is greater than supply.
- Exhaust gases from burning wood chip are at least as polluting as gases from burning coal.

Evaluate the economic, social, ethical and environmental issues associated with the use of wood chip as a renewable energy source.

[6 marks]

Figure 1: Wood chips exam question



The rollercoaster car is raised a vertical distance of 35 m to point **A** by a motor in 45 seconds.

The mass of the rollercoaster is 600 kg.

The motor has a power rating of 8 000 W.

The rollercoaster rolls from point **A** to point **B**, a drop of 35 m.

Calculate the speed of the rollercoaster at point **B**.

Assume that the decrease in potential energy store is equal to the increase in kinetic energy store.

[6 marks]

Figure 2: Rollercoaster exam question

threat of artificial intelligence) by making future exams even more challenging. This is good news for ambitious science educators. Raising the bar means that it isn't enough to just cover the syllabus, the goal of the curriculum should be to prepare students for solving unfamiliar problems.

Novice problem solving

Before we can design such a curriculum we need to better understand what is involved in applying knowledge. I've chosen a particularly challenging specimen GCSE question to illustrate the demands (Figure 2). First, let's imagine how a typical student with fragile knowledge might tackle it I will call them the 'novice' problem solver.

Novice: "Wow, that's a lot of information.
Stay calm, let's take it one sentence at a time.
The rollercoaster goes up to A. Let's write down the values:
I've got the distance, d = 35 m
the time it takes, t = 45 s
the mass of the rollercoaster, m = 600 kg
and the power, p = 8000 W.
It says calculate the speed at B.
And the last sentence tells me that if that the energy at the bottom equals the energy it had at the top.
What equation to use? It's about a motor which transfers kinetic energy to the rollercoaster.
The physics equation sheet says:
Power = energy transferred /time.
I know power and time so I can use that.
I rewrite it: Energy = power x time
= 8000 x 45 = 360000 W.
So if the energy at B is the same, and it's KE,
I can use this equation: KE = ½ mv2
So I put in the numbers:
360000 = ½ x 600 x v^2
v^2 *= 1200*
v = 34.6 m/s."

If you've not taught physics, the novice solution might look correct. They have used the idea of energy conservation, and substituted numbers into the equations. However, the answer is wrong, and that's because the student misread the situation. Let's analyse what they did to highlight key features of the novice approach to problem solving.

First, the student was overwhelmed with all the information. They couldn't make sense of it. Instead of taking in the whole situation they were forced to interpret it line by line. They looked at the problem superficially, writing down key words and values. Then they reached straight for the physics equation sheet. Unfortunately, they selected the wrong equation. Why?

The information about the motor and the energy it transfers doesn't help to solve the question. We don't know how much of the motor's energy is transferred to the rollercoaster. All that matters is its potential energy at the top and the kinetic energy at the bottom - the question actually tell you this. However, it's at the en of lots of information. So many students will have been overwhelemd already and miss the significance.

The main reason novices struggle with apply questions is that there are too many things to think about at once. Not knowing where to start, the novice clutches at straws - keywords they are familiar with and equations that fit the values given. This approach, trying to find a solution as quickly as possible, is called backward reasoning.

Expert problem solving

Experts on the other hand, tend to solve problems in the opposite direction, by forward reasoning. Let's look at how they do it:

"Let's work out what's going on by reading through question.
The last sentence says the GPE lost when the rollercoaster falls equals the KE gained at the bottom.
OK, so the problem is about the principle of conservation of energy - gravitational potential energy = kinetic energy.
I can see I have been given mass and height, so I can calculate GPE from the equation, and I don't need any information about the motor.
I just have to put the equations for GPE and KE together:
$mgh = \frac{1}{2} mv^2$.
The only unknown is the speed, so let's get on and work it out..."

What did the expert do differently? First they didn't dive in. They stepped back to make sense of the situation. Next they homed in on the underlying principle rather than keywords. Its's an energy conservation type of problem. They immediately recalled equations that are typically useful for energy conservation problems. And they planned a strategy to see which equation would work before any calculations. How does knowing about novices and expert approaches help? Because cognitive scientists have come up with a compelling explanation of the differences in terms of memory structures. And knowing this, tells us what kind of knowledge and skill we need students to learn so they can become like experts, rathert than novices.

Working memory

Memory, as you know, consists of short--term and long-term systems. In 1974, Baddeley & Hitch, proposed that short--term memory wasn't just a passive store, it acted as a mental scratchpad where we process and integrate information to solve problems. And the most important feature of this working memory is that can only hold a few pieces of new information at once.

To appreciate this limitation, try some mental multiplication. First, multiply 24 x 9. When you've done it, go back and step through your thinking.

One method is to use a partitioning strategy. You work out 10 x 9 = 90 first. You store the result in working memory, and double it to get 180. Then you recall 4 x 9 = 36, and finally add the sub-totals you were keeping in working memory: 180 + 36 = 216.

Assuming you know a strategy, working memory can cope with the calculation. That is because it only involves storing a few intermediate answers.

Now try the sum 67 x 58. Much harder, isn't it? You could use partitioning again. This time there are 4 calculations: 60 x 50, 60 x 8, 7 x 50 and finally 7 x 8. If you're like me, by the time you have worked out the last sub-total you have forgotten the previous ones, or even where you are in the problem.

What this tells us about working memory is that, when there are too many pieces of information to store, some get lost, and problem solving fails, just like with the novice solving the rollercoaster problem. There are just too many individual pieces of novel information to process.

But how do we explain why experts succesfully solve the problem? For that we need to explore the architecture of long--term memory.

Novice-expert research

Researchers figured out the important differences between experts and novices fifty years ago (Chase and Simon, 1973). Much of the work was done on chess players. The basic experiment is simple, so try it yourself. Draw an 8x8 grid of an empty chess board. Then look at game position shown in figure 3 for 5 seconds. Try to remember the where the pieces are. Look

Figure 3: Chess board

away and then mark all the pieces you can recall on the 8x8 grid. How many did you get right?

Chase & Simon found that novices could only remember the position of 3-5 pieces. They explanation for this is straightforward. Novices attempt to memorise each individual piece but soon fill up their limited working memory.

The result for expert chess players was remarkable. They could recall 16 pieces correctly. The researchers wondered whether this was because they had better memories for chess pieces. So they randomised the positions and found that now, experts were no better than novices. TIn other words, the expert effect was only for real chess positions. In case you didn't figure it out, black can checkmate in three moves (it is hard to spot).

How can experts remember so much? The explanation relies on a feature of long--term memory called 'chunking'. Chunking groups individual pieces of information together. Each chunk only occupies one slot in working memory. So chunking enables our minds to circumvent the limitations of working memory.

A chess expert accumulates large numbers of positional chunks. That is, they don't perceive individual pieces they automatically chunk them together into configurations with a particular meaning in chess e.g. a castled king, or a 3-pawn attack. In the research this enabled experts to remember many more pieces. In the game it free up their working memory space to simulate possible moves and evaluating which gives most advantage. This process of choosing and evaluating strategies is

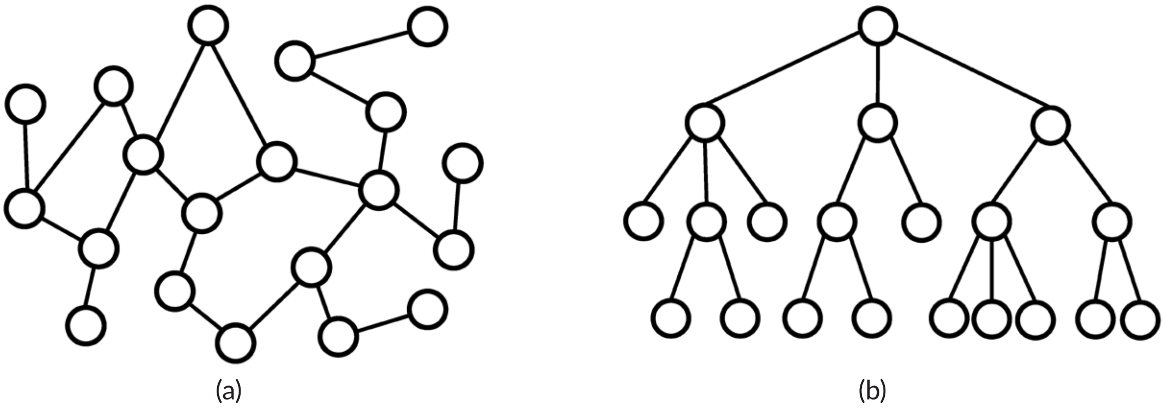


Figure 4: Memory organisation in (a) novices and (b) experts

similar to how the experts solved the rollercoaster problem.

What novice-expert research tells us is that knowledge is not just how much you remember, but how the information is organised. A novice may have crammed lots of facts, but if it they are not connected into meaningful patterns then their knowledge is fragile and problem solving will be difficult. (figure 4a) . Whereas in the expert's mind (figure 4b), knowledge is structured into chunks, which are themselves organised into bigger chunks. This structure enables the expert to detect patterns and connect them to the relevant knowledge for solving the problem.

Schema theory

We can understand the importance of memory organisation better through the lens of schema theory. Schema (Rumelhart, 1988) are very large chunks of related information that are designed to guide our behaviour. You have a schema for every object, situation or event that you have met frequently. For instance, your schema for entering a restaurant tells you to first find the waiter, then get a table, ask for the menu etc. Schema are like templates. They store the general aspects of an object or situation so you don't have to waste working memory on them, and have slots for the things that vary for specific objects, or situations. For instance the 'get a table' step of your restaurant schema has slots to allow for variations like: check your reservation, wait in line, or just sit down at a free table.

Schema are like Russian dolls: general schema are made up of more specific schema, which contain even more specific schema. For instance your restaurant schema may have sub-schema for indian restaurants and fast-food joints, and within fast-food maybe a drive-in McDonalds schema. How does schema theory help our analysis of problem solving?

The physics novice only had a few, skeletal schema to guide them in the rollercoaster problem. Perhaps an energy schema that kicks in when they recognise objects going up or down slopes. Plus a physics question schema that tells them to search for key-

Figure 5: Retrieving the relevant items: (a) novices and (b) experts

words and find a matching equation. Most of the information in their minds is probably disconnected from these schema. Retrieving this information is like finding a book in the middle of a big pile (figure 5a). The lack of rich schema do little to reduce the amount of novel information in the problem, hence the experience of working memory overload.

The expert on the other hand has a rich set of schema. Their energy conservation schema may contain sub-schema for falling object problems like the rollercoaster, as well as stretched spring problems and elastic collision problems. Each one links to relevant concepts and equations. Because the expert's knowledge is so well organised, it is easy to retrieve, rather like finding books in a library using the index (figure 5b).

In addition, experts have detailed schema for how to solve a problem. They know to start by reading the whole problem, mentally representing, then selecting various strategies and testing which one is likely to work best before committing to one.

Curriculum implications

Thanks to cognitive science, we can start to think about how to avoid the fragile knowledge problem and equip students for problem solving. The research has two major implications for curriculum design:

1. Experts' knowledge is structured around the fundamental principles of the subject. So that should the focus of our curriculum goals, instruction and assessment.

2. To maximise space in working memory for problem solving, students need to have memorised concepts, skills and facts and connected them the fundamental principles.

In the next chapter, I will describe what such a curriculum framework looks like.

2. Solution: Big ideas

Synopsis

Many things in life, such as wealth, are not equally distributed. They follow the 80:20 principle - a small number of factors (e.g. people) have a disproportionate influence (e.g. wealth). This law of the few applies to curriculum content - the fundamental science principles matter much more to problem solving than any other content. That means the first job in curriculum design is to take apart the specification and identify these big ideas. They are the key causal principles, models and theories that explain phenomena.

This chapter describes the process that Mastery Science followed to translate the 1000 statements in the AQA GCSE Combined Science specification into a big ideas curriculum map. All the content has to be covered of course, but the curriculum time devoted to each item depends on its importance to the big idea. To help us prioritise, we used an analogy. If the curriculm is like a coach journey through the content, each statements is like an events along the way. Key concepts are the main stops, where you base yourself for a week at a time. We identified 110 of these. From there, you take side trips to the concepts. They need to be understood but are not as fundamental as key concepts so they can be given less time. Finally, you quick photo-stops for the facts. These are statements which only require recall, and can be covered quickly on a slide.

The next step was to decide the curriculum sequence for each of the big ideas. Ideally the concepts within should form a natural progression with concepts that are dependent on others are taught later, and each concept helping students grasp the next. Units are formed by grouping together 2 or 3 related key concepts. Our analysis found that 8 or 9 of these units fitted into the typical teaching time for a year, and that all the GCSE content could be covered in about 4.5 years.

The complete text of this chapter is to be published

3. Problem: Lack of skills

Synopsis

Isaac Newton and Albert Einstein were two of the greatest problem solvers ever. But by all accounts, they were not much good at teaching. Similarly, ask an elite sportsperson what makes them so good, and they are unlikely to give a coherent answer. What we can put into words, called explicit knowledge, is only a small fraction of the knowhow required to excel, called tacit knowledge,

This chapter deconstructs Apply and Analyse questions to reveal the tacit knowledge involved. The conclusion is exam questions are basically miniature versions of scientific enquiry processes. Apply questions challenge students to explain phenomena and hypothesise about causes. Analyse questions challenge them to interpret data and argue with evidence. Much of enquiry skills knowledge is tacit - it has to be learned through experience, not PowerPoint. The implication is that to equip students for Apply and Analyse means giving them opportunities to engage in scientific enquiry processes every lesson.

Question analysis also reveals another dimension of tacit knowledge, which we call underlying themes. For instance, a physicists only thinks about the forces or energy on a specific system of objects, and ignores everything else. Or a biologists looks for form-function relationships, and proximal and distal causes in their explanations. These themes are usually invisible to students. Making them more explicit and helping students to think about them, enables them to develop more expert-like schema.

In Mastery Science's previous framework, the AQA KS3 Science Syllabus, we followed the conventional approach of setting out content and enquiry objectives separately. However, this did little to change the status quo - that content dominates teaching, with enquiry skills practised only occasionally and often only in ritualised practical work. This time we decided that the different elements of science had to be integrated.

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4. Solution 3D goals

Synopsis

Science educators in the USA also concluded that the only way to ensure that students are given the opportunity to learn the tacit knowledge of enquiry and underlying themes was to integrate them in their standards. The 3D nature of science is the major innovation in the latest US curriculum standards.

In this chapter, I describe how we unifyied conceptual knowledge, enquiry skills and underlying themes into the 3-dimensional learning objectives of Blueprint. Before we could do that, we needed a more explicit description of all the enquiry skills and unifying themes than the English National Curriculum provided. Fortunately the US educators behind the standards had made the tacit knowledge of how scientists work into explicit statements about enquiry skills. For Blueprint, we organised these skills into 10 scientific practices. We then integrated them across all 110 key concepts, using a best fit method. As a resulting students will experience each scientific practice multiple times each year.

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5. Problem: Conceptual demand

Synopsis

It takes approximately 10,000 hours to become an expert in a subject. Behind this headline is a body of research which shows that to achieve expertise requires a particular kind of practice, called 'deliberative practice'. Remarkably, Anders Ericsson and colleagues (1993) investigated expert performers across fields such as sports, music and professional scientists, and found that deliberate practice matters more than ability.

This chapter proposes to translate deliberative practice into science education, so that students of all abilities can become expert-like. This requires a shift in our thinking about learning objectives. First, we need to go beyond knowledge objectives and the usual 'describe and explain' language. instead we need to define learning performances - how students can show they have understanding. For instance, Newton's first law, could be turned into a performance about explaining the motion of objects which experience no force. In Ericsson's words, when you focus learning on performance, 'knowledge comes along for the ride'. The Mastery Science curriculum sets out performance objectives for every key concept. Such objectives help in deliberate practice, by making it easier for teachers and students to assess students current performance and give accurate feedback for improving it.

The second obstacle for translating deliberate practice into science is the lack of a clear learning progressions - i.e. the steps students pass through on their way to mastering a key concept. All the fields that Ericsson studied shared this feature, which enables the learner to move along a reliable pathway, focussing on one skill at a time. Can we use what we know about students initial ideas and the goals of understanding to work out the steps that connect them?

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6. Solution: 3 levels of learning

Synopsis

In the computer game Diner Dash, you seat guests in your restaurant, take their order, deliver food and collect tips. What do you learn? Quite a lot, according to some business professionals who claim it taught them how to control resources and satisfy customers. How did it do this without a manual or formal teaching? Players learned from experience. First they performed the basic functions of a waitress. When they mastered that they they moved up a level to face a new challenge. Learning happens through mastering increasing complex performances.

This chapter proposes that we can use the idea of increasingly complex performances to create learning progressions for key concepts. Structuring learning in levels is similar to Vygotsky's 'zone of proximal development' - the level of demand is continually altered to maintain challenge as students' competence increases. They develop knowledge and skills side by by side by engaging in the performances. But unlike computer games, there is teacher input, to explain difficult concepts, and model skills. However, because this is in the context of helping students master a performance, instruction becomes more meaningful than when concepts are taught just because they are on the syllabus.

To provide a sound basis for designing the levels in the learning progression, we used the cognitive processes in the Revised Bloom's Taxonomy and Marzano's New Taxonomy. The 3-level hierarchy they follow is very similar to the 3 Assessment Objectives measured in GCSE. So the unit objectives in Blueprint are set out as 3 levels of increasingly complex performances. They are labelled Acquire, Apply and Analyse.

For AO1, students need to accurately recall in a familiar situation. This is the first level of performance - Acquire. With an appropriate amount of teacher support, students can develop an explanation of a phenomenon to see the value of a concept. AO2 adds the extra challenge of recognising the concept in unfamiliar situations and translating between different representations. This is the second level of performance - Apply. Students need new strategies to solve problems more independently, which we need to teach. AO3 ramps up the demand further by requiring students to interpret new information and make inferences, drawing conclusions from investigations, and making real-life decisions. This is the third level, Analyse.

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7. Problem: Everything's forgotten

Synopsis

In a famous study, undergraduates were asked: what causes the seasons? Most thought it was because the Earth gets nearer the sun in summer. When asked where the mass of a plant comes from, most responded 'from the soil'. Clearly students can remember what they've been taught long enough to regurgitate it in an exam. But it seems they have not integrated the concept into their schema, which makes the them prone to forgetting. So when teachers return to a topic, they have to reteach it.

This chapter argues that in a big ideas curriculum, the focus should be on helping students to restructure their schema, and integrate new understanding. Constructivism is a fundamental principle of learning - what understand largely depends on what they understood before. This means changing the Acquire from the typical approach of transferring information, to one of helping students build the concept out of their existing ideas.

In my view, 'model based inquiry' offers the most promising approach to aligning teaching with how students learn, and with how scientists think. Model-based inquiry starts with an interesting phenomenon, issue or problem that leads to uncovering the concepts and developing the skills. The teacher supports students through a guided inquiry process where student constructs an explanation for the phenomenon. It involves all the usual activities of science - experiments, demonstrations, theories and argument - but in the service of helping students develop a rich mental model, or schema. This is far from the 'discovery learning' approach that has been discredited by psychologists. How does model-based inquiry work in the classroom?

The complete text of this chapter is to be published

8. Solution: Micro-enquiries

Synopsis

In our workshops we set teachers the 'magic paper' challenge. The paper is made of three layers; write on the top one and the mark penetrates to the bottom layer. But the layer in between looks perfectly normal, it is not carbon paper. The teachers' challenge is to develop a model for how magic paper works, in 10 minutes. When we ask afterwards if they want to know the answer, they shout 'yes'. You can see the concentration on their faces as they compare the actual explanation with the one they came up with.

The chapter argues for a similar sequence of activities in acquiring a concept - first explore it, then explain it. The experiments of cognitive scientists, Daniel Schwartz and John Bransford (1998) support reversing the typical order of teaching because of what they call 'a time for telling'. Students make more sense of a theoretical framework after they have had opportunities to explore the phenomenon. The second benefit of Explore before Explain is motivation - exploring makes you curious to learn the concept that explains it. The third benefit is that it gives opportunities to learn all three dimensions of science. Puzzling out magic paper involves hypotheses, predictions, planning experiments and arguing about conclusions. Below, I set out the 6 part structure of Acquire that we have used in our curriculum materials.

- Engage introduces the interesting phenomenon. At this stage, we find out what the students already know, and check their relevant prior understanding.
- Enable is a stage of pre-teaching to introduce basic concepts and skills, to start building a model and to help students think with in the Explore stage.
- Explore is based on a focussed question about what causes what that is designed to uncover the key concept to be learned. A well designed Explore task gives students the right experience to make sense of the explanation to follow.
- Explain starts with students' explanations and puts these into a theoretical framework based on the key concept. It introduces further curriculum content.
- Epilogue is where the students, under teacher guidance, unravel the puzzle, using the key concept to explain the phenomenon.
- Extend helps to generalise the concept beyond the initial context, with additional examples and related concepts.

The complete text of this chapter is to be published

9. Problem: Lack of engagement

Synopsis

Imagine teaching football like this: "Today we're doing the offside trap. Here is the rule: if you play a ball in the attacking half of the field, then no player can be nearer the goal line than the next-to-last opponent. I'll give you some examples, and then some questions to do. When we play a game at the end of term, you can try it out." How many students do you think would look forward to football? Or be able to use the offside trap?

Unfortunately, this is how we often teach science, by divorcing the principles from how they are used. Rarely do students get to play the game of science. It is surely part of the reason students switch off the subject as they move up the school. Although motivation is not the overal goal of science, it's strongly linked to performance. Students who are motivated will put in more effort. And restructuring concepts and practising to mastery require a lot of effort. How can we make science more motivating to learn?

This chapter proposes making science more authentic. That means giving students tasks students where they think act, and feel like scientists. As I argued in chapter 3, experiencing the doing is how students gain the kind of tacit knowledge they need to cope with Apply and Analyse questions.

Some people believe that acting like a scientist is too hard, that it overloads students' working memories. Certrainly full on research would be beyond most students. But as designers, we can structure and scaffold tasks so that they are within students capacities,. We can use direct instruction, modelling and examples when it's more efficient - and let students work things out for themselves when they can. Sports teachers uses whole-part-whole teaching to balance authentic learning and direct teaching. First students see the whole - the problem they are going to solve. Then, the teacher breaks down performance and students work on the parts - skills and concepts. Finally, students connect the parts together in the game. How can we apply this to science to make it more authentic?

The complete text of this chapter is to be published

10. Solution: Authentic tasks

Synopsis

Brazilian footballers possess amazing skills. Until a few years ago, few people knew why. The reasons is that children learn through a junior version of the game, called 'futsal'. With its small pitch and heavy ball, children get more touches than in a regular game and are rewarded for fast thinking and intricate passing. Essentially futsal acts as an ideal practice environment, for learning the parts and integrating them into the whole.

In this chapter, I describe the science equivalents of futsal, Discovery, Decision-making and Decision, and how they can be integrated into a teaching sequence. The classical science game is Discovery, where scientists get interested in a phenomenon and develop a theory to explain it. A junior version of Discovery involves constructing problem that is interesting enough to engage students, but are not too difficult for them to solve. Ritualised practicals don't count.

The games of Decision-making is that citizens and science professionals play. They work out how to solve energy problems, choose the best medical treatment, or how to evaluate products. We have created many junior versions of Decision-making to get students interpreting information and communicate their views, just like they do when they answer AO3 exam questions. The third game, Design, is what engineers play. They make model, test and refine solutions using scientific knowledge and enquiry processes. Many junior Design tasks exist such as making devices to purify water, or crumple zones to protect an egg.

The main problem with authentic tasks is justify their curriclum time. Our framework includes an Act stage which frames the unit within an authentic task. The problem is introduced at the beginning e.g. in an interdependence unit the Decision-making problem could be: how can we stop mosquito-borne diseases? The whole is then broken into parts by teaching the key concepts of food webs, competition and biotic/abiotic factors. Finally students integrate the parts into the whole, by considering the evidence and arguments and coming to a decision. Act also functions as a performance assessment.

The complete text of this chapter is to be published

11. Problem: Differentiation

Synopsis

In the 1980s Benjamin Bloom of taxonomy fame, wrestled with another question: how could teachers in a class of 30 students achieve similar learning gains to those of 1:1 teaching? He realised that the fundamental constraint of teaching is the difficulty of tailoring learning to individuals needs. Typically, curriculum time is a constant - teachers move on when they have finished a topic. In Bloom's system, time is a variable - students have longer to master the material when they need it.

This chapter describes the key features of a mastery system that enables more individualisation. Mastery learning combines features of assessment for learning and deliberate practice. It is based on the idea that teaching adapts to the learner and that feedback is tailored to where each student is, the skills they need to improve, and what to work on next.

Mastery learning therefore requires regular and accurate formative assessment to check whether students have mastered each objective. After every formative assessment, there will be at least two pathways - re-learning for students who did not meet the threshold and more challenging activities – on the same content – for those that did.

Mastery learning requires a lot of forward planning and materials - it is difficult to manage in practice. So it is not surprising that, despite its research base for impressive achievement gain, its popularity faded. How can we make the system simpler to use and reduce the workload involved?

The complete text of this chapter is to be published

12. Solution: Adaptive teaching

Synopsis

Assessment for learning should have caused a revolution in teaching and learning. Uniquely it was backed up by research, supported by government, and widely adopted by schools. Yet, most commentators agree that it failed to have much impact. One reason is that it was viewed as assessment. As Dylan Wiliam has reflected, it's not the data capture that matters but how you use it to individualise learning.

This chapter describes the system for adaptive teaching in science that we have integrated into the Blueprint curriculum framework. It adds two formative assessment checkpoints in the learning pathway, Activate and Assess, to complement the three learning stages of Acquire, Apply, and Analyse. The result is a 5-step learning progression (5As) for each key concept.

Activate checks whether students understood the prerequisite concepts before teaching. This is like a doctor diagnosing what a patient needs before giving a prescription. If the pre-assessment determines that students lack a prior concept, teachers can immediately fill gaps in knowledge, or adapt later teaching to take account of misconceptions.

Assess is the diagnostic stage after teaching. It answers the question: did they get it? One way to find out is to administer a diagnostic multiple-choice quiz. This has the advantage of giving immediate feedback, and questions can be constructed with distractors to reveal misconceptions. Assess is linked to Analyse. Students that have grasped the concept move to the most challenging activities to develop their higher order thinking.

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