Teaching Secondary Science by *Adam Boxer* **(2021)**

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Content	**Questions/Thoughts**
Introduction/Structure/General reading Book = personal realization (through reading) that some practices (direct instruction (di)) more effective than others (discovery learning), includes concrete suggestions/shared language. Book is theory light/ helpful/practical/science-specific.	• Book → helps others to improve, avoid isolation, practical, concrete ideas • See https://cogscisci.wordpress.com/
Part 1: Substance Chapter 1: Where to start? Curricula can be low specificity, decide core qs (CQs) you want answered, differentiate school subject knowledge (SSK) from pedagogical content knowledge (PCK) AND procedural K (K how) vs declarative K (K that), CQs good for declarative K. **Chapter 2: Which knowledge matters?** Science can be hierarchical; always need to identify what they need to know to access CQs = prerequisite K (PK), write questions to identify if it's there (PKQ) **Chapter 3: Starting the learning sequence** Ss are not blank slates. They have domain knowledge (DK), need to check the correct DK, get data at the start with PKQ = retrieval practice (RP.) – tell them rationale for RP. Clarify means of participation (MoP) →notes/where do answers go/what if they don't know/full sentences/write q? Build a culture of participation. **Chapter 4: Books, mini-whiteboards (MWB) or oral response – what works when?** For PKQs: bookwork (participation ratio high, hard to get whole-class data, MWB), targeted qs (encourages high level language, only a few Ss, see Lemov Cold Call/Wait Time/No Opt Out), MWB (quick, full participation, need routines) **Chapter 5: Types of question** Need range of qs: short answer (SA) (can be simple declarative, or application), T/F/MCQ (quick but recognise ≠ reproduce, data you get is limited, calculations take time, use diagrams with care). **Chapter 6: The challenge equation** $CHALLENGE = \frac{task\ quantity}{DK+support}$ Task quantity (TQ) = no. of things in the question, DK = fluid/changeable, support = cues, keywords, can be verbal, written, diagrammatic. **Chapter 7: Many birds, one stone** Spacing aids retrieval, quiz with range of spaced qs + go over as whole class = settles, routine of long-term learning (has benefits re. self-determination theory - see Ryan & Deci), then MWBs for PK. **Chapter 8: Going over your retrieval quiz – the basics** 2 type of question: monosemic (single correct answer e.g. where is bile produced?), polysemic (multiple correct answers e.g. what is an atom?). Sample Ss answers, clarify what/why it's correct, write correct answers on the board, Ss mark own work. **Chapter 9: Going over your prerequisite quiz** What if PKQs on MWB show weak understanding of PK? Re-teach/explain weak areas then more (detailed) qs on MWB to check for understanding (CfU).	• Make CQs detailed + highly specific • Ensure YOU have SSK AND PCK • Plan learning sequences from content not resources • Carefully identify PK, make PKQs • Check they have PK they need with quiz & aim for lots of success • Maker routines for RP clear from start • Be aware of participation/thinking ratio • Make MoP a conscious choice • Incorporate thinking time with all qs • Need range of qs to elicit data on all PKQs • Balance time for responses with quality of data responses produce • Evaluate 'challenge' of each question - TQ easiest to manipulate • Make difficulty 'desirable' but avoid cognitive overload (see Sweller CLT)) • Space out RP of DK over weeks/months • Normalise 'wrongness' by explaining how & why someone might get it wrong • Going over gets data + improves Ss K • Plan for reteaching PK + additional Qs • Remember: performance ≠ learning
Part 2: Explanations Chapter 10: Explaining science Use the CHALLENGE equation to guide route through. Experts (teachers! (Ts)) have knowledge that is organized differently, can struggle to understand issues novices face (curse of knowledge). **Chapter 11: Sequencing examples** needs: careful planning including non-examples → elicit boundary conditions to concepts. **Chapter 12: The multimedia effect** = learn more from images + verbal info at the same time (dual coding explains this). If separate → split-attention effect e.g. recipes. Listening + reading → redundancy effect e.g. reading from slides. Both avoided by building up diagrams in real time. **Chapter 13: Making the abstract concrete** Need to amend: $CHALLENGE \frac{TQ+abstraction}{DK+support}$. Ss have limited working memory (WM), easily overloaded, hard to make mental image of abstract concept. **Chapter 14: Explanations in action - digestion** → see book for detailed example (live diagrams) **Chapter 15: Analogies** have: source (what is known), target (new thing), inference that links the two. Use them when: Ss are familiar with source, the source → target not too much stretch/ believable, not distracting (no celebs), doesn't promote misconception, is necessary! **Chapter 16: Directions of travel (DOT)** like concrete → abstract or familiar → unfamiliar. 1. Wood→ Trees→ Wood (aka Zoom Out/In to see bigger picture, the 'why') 2. Simple → Complex (learning the complex can take years) 3. Example→ Principle→ Example (can concretize the principle faster to vary order) 4. Explanation → Definition (definitions can be v. unfamiliar/off-putting) 5. Hinterland → Core (can set the stage/ make connections to Core easier) 6. Conflict → Resolution (set up as a story). **Chapter 17: Misconceptions** are plausible/predictable, better to think 'misconception character' (high: sun goes around Earth/low: respiration = breathing/not: ribosomes contain DNA). Little solid practical advice from research. Know what they are, mitigate effect by dealing with abstraction. **Chapter 18: Explanations in action - diffusion** see book for detailed example (using CQs/non-examples). **Chapter 19: Explanations in action – the heart** see book for detailed example (simplifying complex live drawing). **Chapter 20: Introducing new vocabulary** Remember simple → complex DOT, use explanation → definition DOT a lot to teach meaning then define after. **Chapter 21: Explaining equations** Solving equations = transferrable skill, understanding meaning of equation is not; needs quantitative AND qualitative approach by 1. Teaching what variables mean 2. Start with concrete variable 3. DOT → abstract variable 4. Do simple ratios/diagrammatically/ build to simple numbers 5. Use accumulations (e.g. energy = power x time, distance = speed x time) **Chapter 22: Solving equation problems** Care with cognitive overload, significantly reduce TQ at the start (whole numbers, broken down, small steps), view as building a skill set over the long-term. Pick a method that works (READ about it before you use it!). **Chapter 23: Engaging explanations** Remember attention is fragile: care when asking questions during explanation (increases participation ration, can be disruptive), jokes/personal stories (use carefully, can split attention).	• Always go from familiar → unfamiliar • Novices are NOT little experts • Beware expert blindness • Teach what it 'is' AND what it 'is not' • Splitting attention increases TQ • Construct diagrams from blank canvas, talking as you go (rehearse this) • Use images to move from concrete to abstract/provide support/mental model • Choose analogies with care and use 'use them when' checklist ← • If not really necessary, may still engage. • V. important they 'see the big picture' • Learning some concepts can take years • Definitions first doesn't always help • Use Hinterland judiciously, with care • Stories cognitively privileged • Anticipate misconceptions from your domain knowledge/research • Misconceptions are tricky to change because they ARE plausible/ possible • Check all vocab – Tier 2 AND Tier 3 • Teaching vocab adds to TQ – careful • There are issues with 'transferable' skills but solving equations is transferrable • Important that Ss know meaning of equ^n. • Formula triangles ≠ meaning, do NOT use • See FIFA, EVERY, Bunsen Blue, FICSU methods (available online) • Limit the 'teacher-led disruption' via humor by using judiciously • If attention lost→ pick up from much earlier point.

Part 3: Building Understanding Chapter 24: What is understanding (U)? Ill-defined, can be: subjective feeling (but reject self-reporting of feeling = K), perception of deep structure (can be superficial), integration of new K with old K (into a 'schema' = organizational structure of K in LTM). ***U = solidifying new K + extent of connections to prior DK*** → a spectrum. Teacher moves Ss along spectrum by: PKQs, explanation, CfU, independent deliberate practice. **Chapter 25: Check and consolidate** New K is initially hazy/ephemeral, do not understand *enough*. Explanation → CfU → con*solid*ation (make new K *solid)* by verbalizing/writing (e.g. Turn & Talk, sampling via MWB). **Chapter 26: The 'quick and dirty' – check and consolidate (QDC&C)** → E.g. remove labels from diagram, replace w/a, b, c etc. Ask qs about each (name/purpose/differences/why/what if)	• See Bartlett – schema theory • New ideas can 'feel like they make sense' but not be solid/connected to prior DK. • We are in the schema building business (long-term, not rote memorization) • Can be overlap CfU/consolidation – both needed before practice e.g. QDC&C • Pareto: 20% of teacher effort → 80% of student outcomes (probably)
Part 4: Independent Practice Chapter 27: Practicing procedural knowledge - equations Evaluate practice qs with the CHALLENGE equation, need careful design/sequencing (not 'easy' → 'hard', *all* should produce learning). Increase challenge by: TQ (unit conversions/more steps/finding data), reducing support, care with decimal numbers → increases abstraction. **Chapter 28: Interleaving** = mixing qs from different topics (vs. blocked practice = same topic). Works to: break algorithmic routine (when blocked), space retrieval, elicit similarities/differences. **Chapter 29: Practicing procedural knowledge in action - speed** see book for detailed example (teaching equations, CfU, consolidation). **Chapter 30: Practicing declarative knowledge** → More challenging than procedural K, less variation possible. Techniques: 1. Spacing slightly varied repeat. 2. Contrast concepts (e.g. SHC/SLH) 3. 'If it didn't…' (elicit structure & function e.g. if a sperm didn't have a tail) 4. Give a wrong answer + ask why. 5. Because/but/so (e.g. metals conduct…). Interleave for same reasons as in procedural K. **Chapter 31: Expertise reversal** → Effect = what is effective for novice Ss (NS) (chunking, worked examples, direct instruction etc.) is less effective for expert Ss (ES). Think CHALLENGE equation: as Ss move along spectrum: NS → ES support ↓, TQ↑ as DK&U↑.	• Worked examples work IF they're thinking – sampling/MWB needed • Practice increases DK • Vary qs by varying variables in CHALLENGE equation • Incorporate interleaving purposefully • Question sets might (need to be) long • Declarative K needs more variation in types of q – model how to answer them • See CogSciSci website for more options • ES need much less structure – can be counter productive/frustrating • Goal-free questions (with text/ diagrams) suit ES not NS.
Part 5: Assessment and Feedback Chapter 32: Assessing understanding A 'literal' test checks one bit, can't test everything they should have learned, need to give 'representational test' – sufficient qs to infer K of the whole. Can also use QDC&C to get data – assuming level of challenge is right. **Chapter 33: Feedback** On a spectrum: directive (instantaneous, work-focused) → non-directive (time-lagged, student-focussed). Directive at the start → non-directive with time/teaching. **Chapter 34: What to do after an exam** Plan 'going over the test' with care. Do question level analysis (QLA) to see patterns/issues - note down what to reteach/put in RP/do differently next year **Chapter 35: Marking and whole-class feedback** Comment based marking inefficient (and arguably ineffective without class time given for action). Instead, Whole Class Feedback (WCF) efficient/effective: get info from: 1. Noticing issue in indep. practice 2. Sampling some books, see common errors 3. Short test/assessment then go over/CfU/continue. **Chapter 36: Reviewing independent practice** Don't just give out the answers: Cold Call/no need for Wait Time/Bounce to other students/keep thinking ratio high/write longer answers on board/sample numerical answers/require listening	• Move from literal (at start) to representational (after time/teaching) • Write QDC&C that reflect ↑ • Type of feedback will change • They'll just focus on the test grade, alas • Reteach problematic content from QLA • Don't go over question by question • WCF much less time-consuming than writing comments – limited evidence they improve learning. • Circle during Indep. practice to see common errors • Make review as active as possible
Part 6: Practicals Chapter 37: The art of the demo Ask 'why am I doing this demo?' 1. Awe & wonder: links to 'unexpected', helps to set up conflict → resolution DOT 2. Teach content: make the abstract → concrete, narrative approach, support with diagrams alongside, follow with QDC&C. **Chapter 38: Problematic practicals (Ps)** Benchmarks: 1. School needs policy re. purpose/place of Ps within other learning 2. Ts should know how to do Ps effectively. Many reasons for Ps. Problems: high TQ & abstraction/low DK of Ss/hard to support. **Chapter 39: The Slow Practical** 1. Break down P into smaller steps 2. Combine Ss P activity with T demo. Benefits: all manageable, easier to see issues/risks, can continue to explain throughout, learning is clearer to Ss.	• Brains are prediction machines – surprise/counterintuitive works well • Pair demo with visual prompts • Sort out school policies re. Ps • Practical worksheets → TQ very/too high • Break it down with Slow Practicals = wood → trees → wood DOT
Part 7: Building Brilliant Scientists: Chapter 40: Mary, and why we teach science Learning science → 'new' DK that gives alternative perspective, deepens/enriches experience of the world, produces tech achievements, glimpse of how scientists think, informed citizenship. **Chapter 41: Motivating scientists** Engagement is a poor proxy for learning. We can help motivate by 1. Explaining the why of learning (the more you know the easier it is to learn) 2. Giving success → breed confidence → motivating. **Chapter 42: A culture of retrieval** RP is a long-term strategy that is contained in 1. Fixed-point quizzing (see Ch1) 2. Before/during explanations (see Ch9) 3. During practice (see Ch28) 4. Homework (builds a Culture of Retrieval – see Carousel Learning for easy-to-use system with excellent feedback for teachers: https://www.carousel-learning.com/)	• Reasons for teaching science not mutually exclusive • All answers to 'why do we teach science' mean more DK for Ss is better • Be wary of gaming for sake of engagement – they may learn nothing • Set homework purposefully as part of long-term RP strategy • Check out Carousel Learning
Conclusions Happy Science Teaching! Advice from FAQs: 1. Don't try everything from this book – do a chunk at a time. 2. Differentiation – not useful term, use CHALLENGE equation instead 3. Curriculum sequencing – very time consuming. 4. Student talk: answering qs, Turn and Talk, whole class reading, paired quizzing are good places to start. 5. Leson Objectives (LO) never: grade them/use all/most/some/differentiate by command work/have Ss spend ages copying them/say them at the start. 6. Frequency of assessment: frequent CfU/C&C, infrequent tests. 7. Getting Ss to read the q. 8. Exit tickets: don't teach to the bell. 9. Metacognition: what does It mean? 10. Taking notes: should not be copying 11. Projects: time-consuming, can learn little 12. Hands-on learning: hard to know what learning is happening 13. Working scientifically: not different to other K, needs explicit teaching using CHALLENGE. 14. RP starter takes too long: Ss don't have enough DK for your qs, build slowly. 15. Is this book everything I need? No, but great start… now read some more!	• Well sequenced lesson = good use of time, more than whole curriculum • LOs are for you at start, Ss at the end • Think through assessment framework • Teach Ss to work back from answer to q rather than to read the q • Ss can't listen + write + think at the same time –so can't 'take notes' like that • Working scientifically/scientific method vocab is highly abstract, needs teaching • Join the community of evidence – based science teachers!