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Science: what should we teach and how should we teach it?

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What’s the issue?

“Scotland should consider updates to some of its vision’s core elements and their implications for practice, in particular, the role of knowledge in CfE”

OECD (2021), *Scotland’s Curriculum for Excellence: Into the Future*, Implementing Education Policies, OECD Publishing, Paris, https://doi.org/10.1787/bf624417-en.

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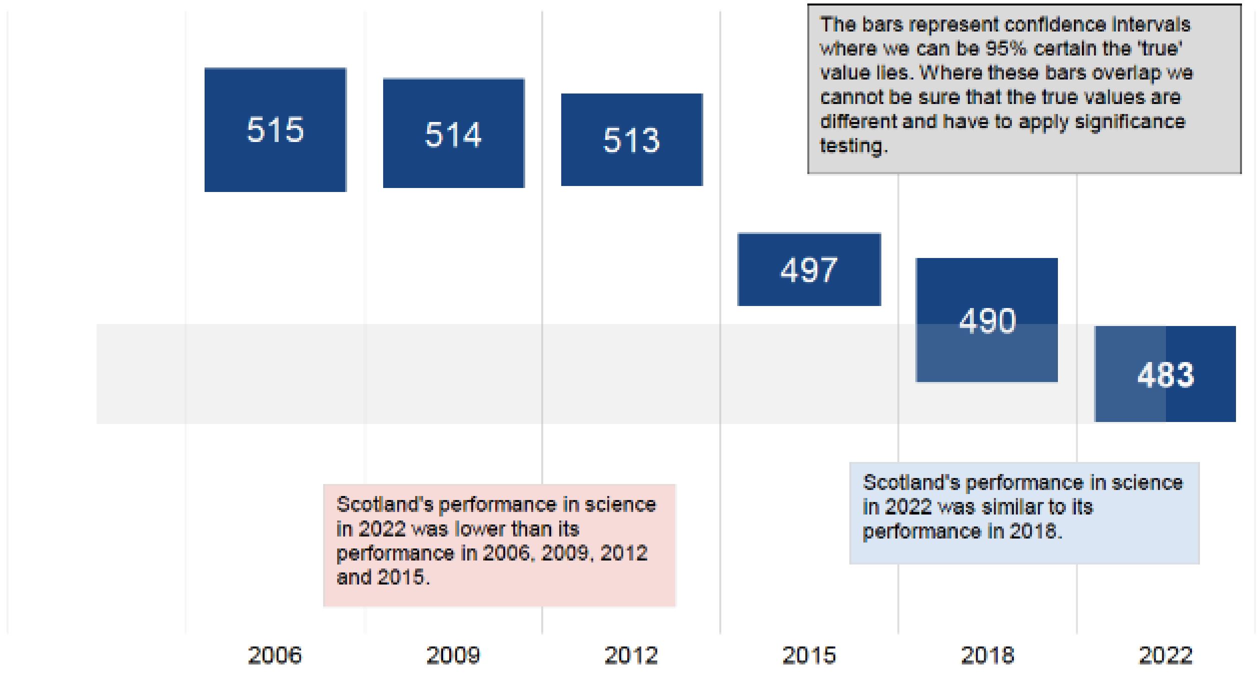
What's the issue?

Chart 4.1.1 Scotland's PISA science scores, 2006-2022



(From https://www.gov.scot/publications/programme-international-student-assessment-pisa-2022-highlights-scotlands-results/pages/5/#Chart4.1.1)

Chart 4.1.4 Scotland's science scores, by PISA Proficiency Level, 2006-2022

103. As set out in Annex 2, the OECD categorise students into levels according to their ability to undertake certain tasks. However the group below Level 2 merits particular attention, as the OECD consider that Level 2 is the baseline of proficiency in science. In 2022, 24.0 per cent of students in Scotland performed below PISA Level 2 in science. This was similar to 2018, but higher than 2006, 2009, 2012 and 2015.

104. In 2022, 6.8 per cent of students in Scotland performed at PISA Level 5 or better in science. This was similar to 2012, 2015 and 2018 but lower than 2006 and 2009.

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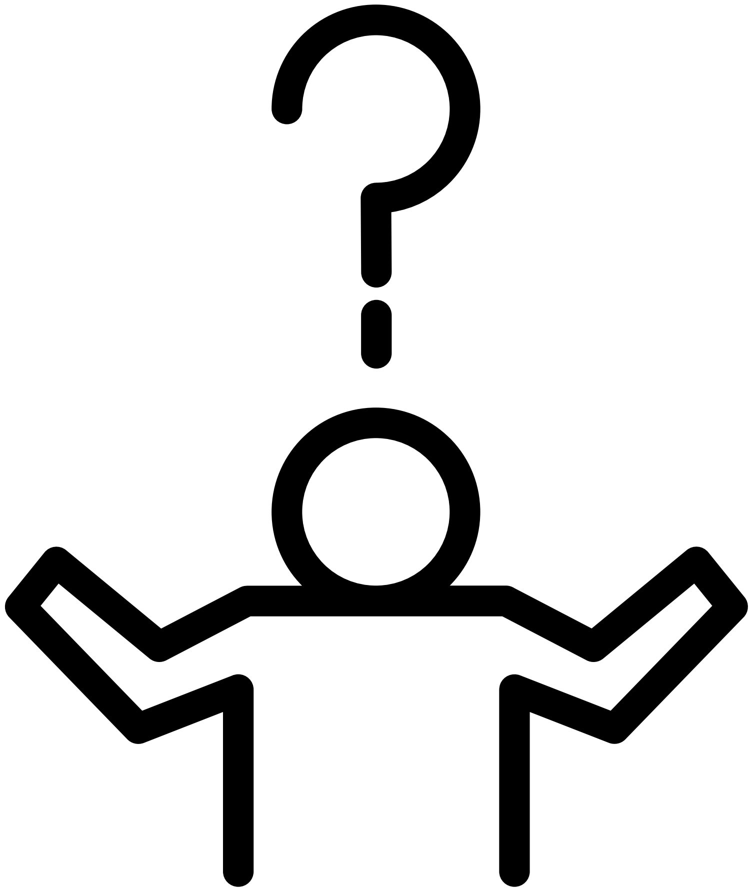
A refreshed science curriculum

Why? What? How?

https://mrpriestley.wordpress.com/2024/04/23/the-position-of-knowledge-in-curriculum-for-excellence-a-response-to-the-paper-tabled-at-cab-30-01-2024/

Why science?



What knowledge?

Table 1: Knowledge can be categorised according to its disciplinary nature and how it is used by an individual

	Substantive knowledge	Disciplinary knowledge
Conceptual… know that… because…	Liquids expand when they are heated (for example, the liquid inside a thermometer).	All measuring instruments, such as a thermometer, have a built-in degree of uncertainty.
Procedural[footnote 73]… know how to… and be able to…	Draw a particle diagram for a liquid.	Use a thermometer to measure the temperature of a solution.

OFSTED. (2021). *Research review series: science. Retrieved from https://www.gov.uk/government/publications/research-review-series-science*

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What knowledge?

- Learn science?
- Learn about science?
- Doing science?
- Addressing socio-scientific issues?

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International journal of science education, 36(15), 2534-2553*. (£££)

What knowledge?

Ideas *of* science

1 All material in the Universe is made of very small particles.

2 Objects can affect other objects at a distance

Ideas *about* science

11 Science assumes that for every effect there is one or more causes.

12 Scientific explanations, theories and models are those that best fit the facts known at a particular time.

13 The knowledge produced by science is used in some technologies to create products to serve human ends.

14 Applications of science often have ethical, social, economic and political implications.

Harlen, W. (2010). *Principles and big ideas of science education. Association for Science Education.*

Are we serious about social justice?

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How do we teach science?

In the sciences, effective learning and teaching depends upon the skilful use of varied approaches, including:

- active learning and planned, purposeful play
- development of problem solving skills and analytical thinking skills
- development of scientific practical investigation and inquiry
- use of relevant contexts, familiar to young people's experiences
- appropriate and effective use of technology, real materials and living things
- building on the principles of Assessment is for Learning
- collaborative learning and independent thinking
- emphasis on children explaining their understanding of concepts, informed discussion and communication.

Through involvement in a wide range of open-ended experiences, challenges and investigations, including those related to the applications of science in areas such as engineering, medicine and forensics, children and young people develop skills of critical thinking and appreciate the key role of the scientific process both in generating new knowledge and in applying this to addressing the needs of society.

https://education.gov.scot/media/111nhizk/sciences-pp.pdf

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What does CfE say?

I have collaborated on investigations into the process of photosynthesis and I can demonstrate my understanding of why plants are vital to sustaining life on Earth.

SCN 3-02a

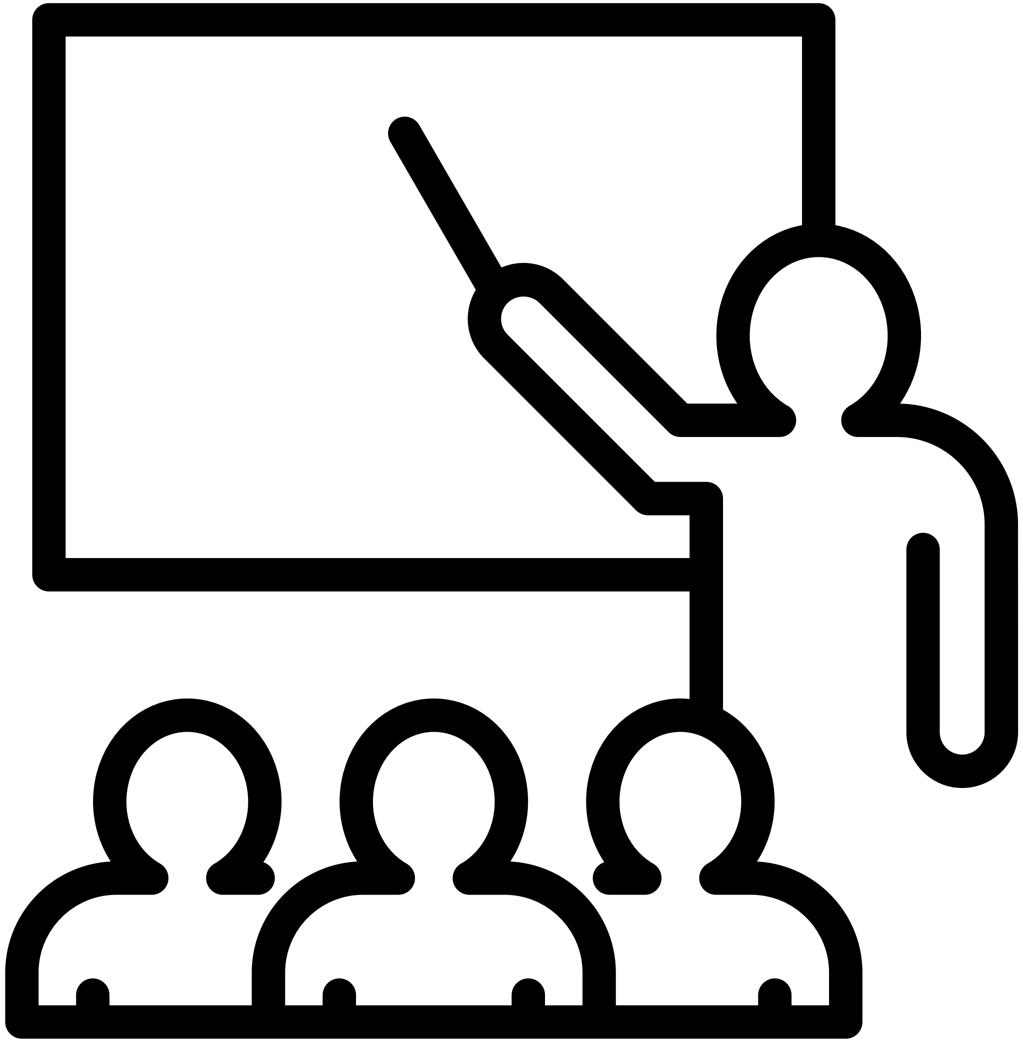
By contributing to experiments and investigations, I can develop my understanding of models of matter and can apply this to changes of state and the energy involved as they occur in nature.

SCN 3-05a

Through investigation, I can explain the formation and use of fossil fuels and contribute to discussions on the responsible use and conservation of finite resources.

SCN 4-04b

What’s missing?



What’s the evidence for explicit instruction?

- Controlled studies
- Correlational studies
- Cognitive architecture

Zhang, L., Kirschner, P. A., Cobern, W. W., & Sweller, J. (2021). There is an Evidence Crisis in Science Educational Policy. *Educational Psychology Review. https://doi.org/10.1007/s10648-021-09646-1*

Controlled studies

- Various controlled studies show benefit of explicit instruction over minimally guided methods
  - See Zhang *et al* (2021) for examples

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“…evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the learning process. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge…”

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational psychologist*, 41(2), 75-86.

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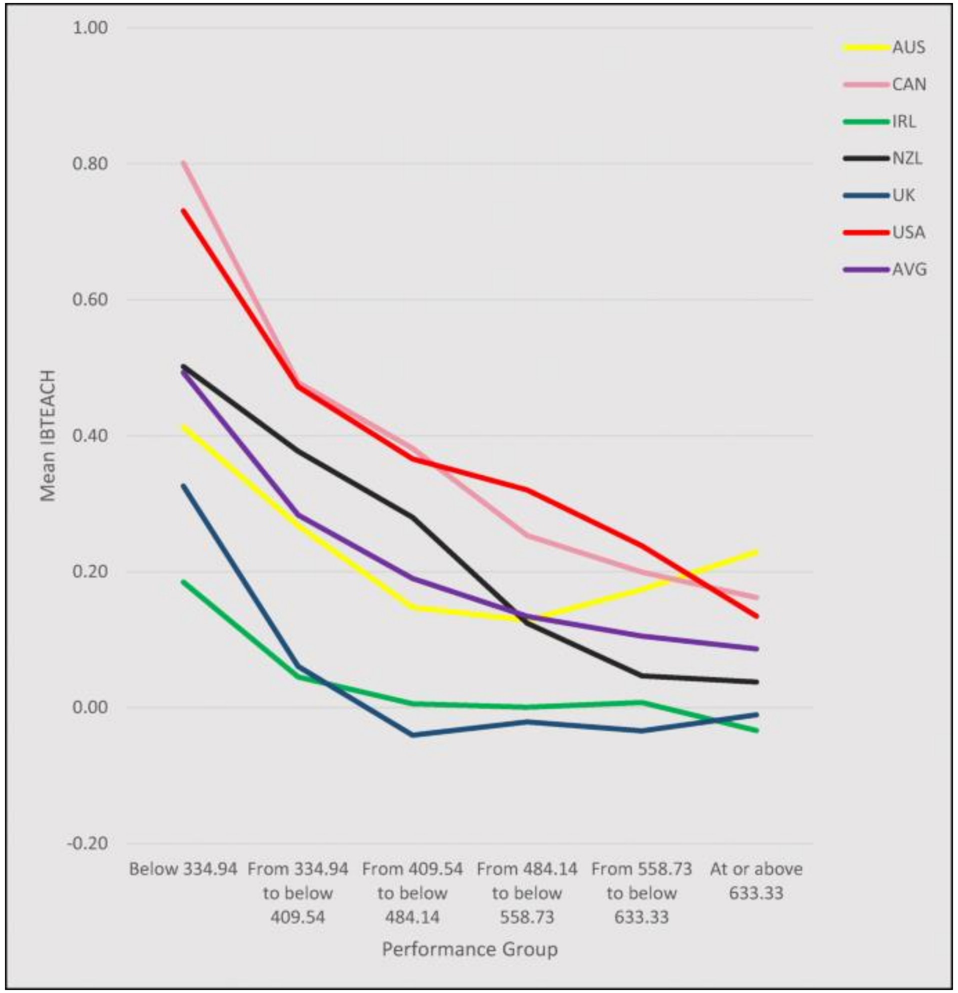
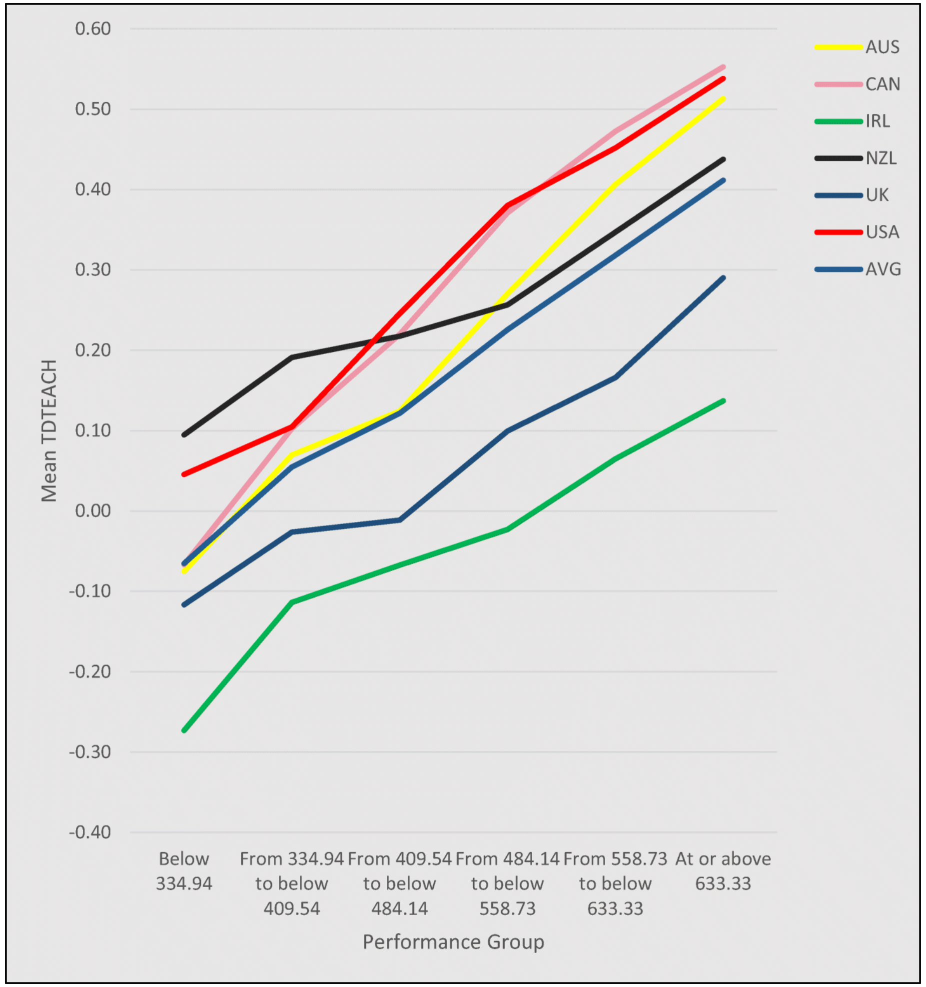
Correlational Studies





Oliver, M., McConney, A. & Woods-McConney, A. The Efficacy of Inquiry-Based Instruction in Science: a Comparative Analysis of Six Countries Using PISA 2015. *Res Sci Educ* **51** (Suppl 2), 595–616 (2021). https://doi.org/10.1007/s11165-019-09901-0

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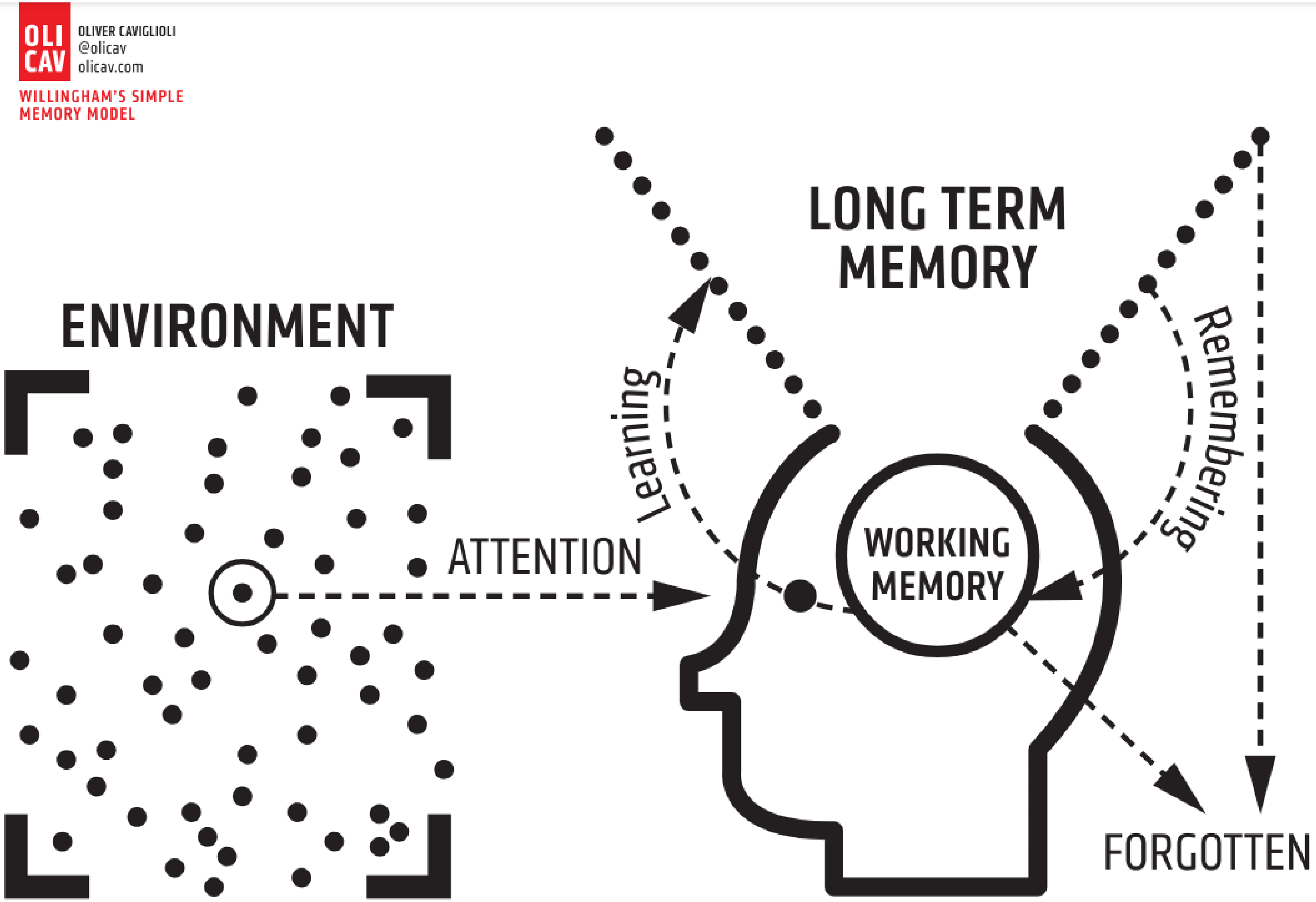
Key Findings

- New Zealand students experience high rates of *teacher-directed science instruction*. Teacher-directed science instruction appears effective at raising students' scientific literacy.
- The effectiveness of inquiry-based science instruction appears highly variable. Moderate use is unrelated to lower student performance, although not as effective as teacher-led methods.
- At high levels of use, inquiry-based science instruction shows a problematic relationship to achievement and the precautionary principle suggests this level of use should be discouraged.
- Inquiry-based methods show value in helping students develop positive attitudes to science.
- There is a generalisable 'sweet spot' combining both methods, with teacher-directed methods in most to all classes and inquiry-based in some, with the inquiry-based instruction supplementary – e.g., as an end-of-module extension – to a general strategy of teacher-directed instruction.
- To be effective, inquiry-based instruction relies on good school discipline, pre-teaching of key content, as well as adequate teacher guidance, teacher planning time and school materials.

Jang-Jones, Adam. (2019). Inquiry-based or teacher-directed science? Evidence from PISA.

Cognitive architecture



“According to our definition, explicit teaching requires novices to be provided with full explanations of new concepts and models of new procedures. Once they are no longer novices, activities similar to those used in episodes of enquiry learning become more appropriate…”

Sweller, John, Lin Zhang, Greg Ashman, William Cobern, and Paul A. Kirschner. *Educational Research Review*.

Point change in PISA[1] science score relative to baseline,[2]
average score increase or decrease

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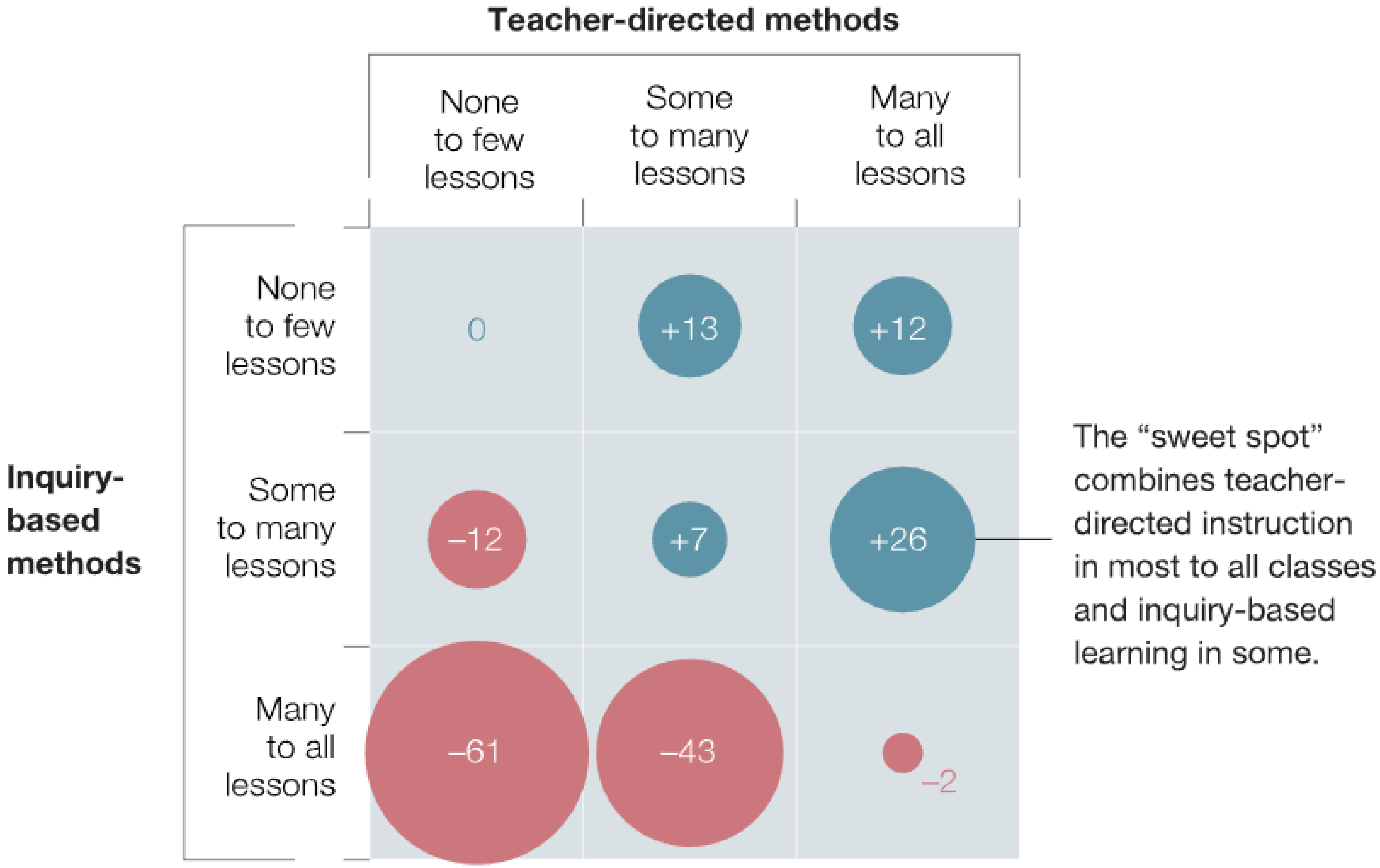

https://www.mckinsey.com/industries/education/our-insights/how-to-improve-student-educational-outcomes-new-insights-from-data-analytics

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"We subsequently argue that inquiry-based and direct instruction each have their specific virtues and disadvantages and that the effectiveness of each approach depends on moderating factors such as the learning goal, the domain involved, and students' prior knowledge and other student characteristics. Furthermore, inquiry-based instruction is most effective when supplemented with guidance that can be personalized based on these moderating factors and can even involve providing direct instruction. Therefore, we posit that a combination of inquiry and direct instruction may often be the best approach to support student learning. "

de Jong, T., Lazonder, A.W., Chinn, C.A., Fischer, F., Gobert, J., HmeloSilver, C.E., Koedinger, K.R., Krajcik, J.S., Kyza, E.A., Linn, M.C., Pedaste, M., Scheiter, K., Zacharia, Z.C., Let's talk evidence – The case for combining inquiry-based and direct instruction, *Educational Research Review* (2023), doi: https://doi.org/10.1016/j.edurev.2023.100536. (£££ I think)

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“Attending orderly classes in which students can focus and teachers provide well-paced instruction is beneficial for all students, but ***particularly so for the most vulnerable students****”*

Agasisti, T., Avvisati, F., Borgonovi, F., & Longobardi, S. (2018). Academic resilience: What schools and countries do to help disadvantaged students succeed in PISA.

3

Ensure all pupils have access to high quality teaching

— explicit instruction;

— using technology to support pupils with SEND; and

— scaffolding.

— cognitive and metacognitive strategies;

— explicit instruction;

— using technology to support pupils with SEND; and

— scaffolding.

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[Cullen, M. A., Lindsay, G., Hastings, R., Denne, L., & Stanford, C. (2020). Special Educational Needs in Mainstream Schools: Evidence Review. *Education Endowment Foundation*.]

Recommendations

- Decide *why* we are teaching science
- Reinstate the importance of knowledge
  - Decide on what knowledge is to be included
  - Will lay foundations for developing the skills we desire
  - Give teachers time to lead these discussions
- Acknowledge the importance of explicit instruction from an expert teacher
  - Inquiry based learning can be introduced as pupils become ‘expert’ in a topic

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