Applying cognitive science principles to primary science

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INTRODUCTION

Cognitive science provides insights into learning that can inform practice in education, but the plethora of publications and, in some cases, the lab-based nature of studies that are remote from classroom realities make it difficult for practitioners to use this evidence to support or adjust their teaching. Considering subject-specific applications of cognitive science offers one way forward. In this article, we will explore two ways in which cognitive science principles can be applied to the teaching of science in the primary school. Approaches to managing cognitive load and retrieval practice will be exemplified, with reference to examples drawn from the Teacher Assessment in Primary Science (TAPS) project (web link in the references). TAPS works with teachers across the UK to co-research practice and co-develop resources to support the teaching and assessment of science in primary and Early Years settings.

MANAGING COGNITIVE LOAD

The prevailing model of learning in cognitive science is that knowledge exists as patterns of connections between brain cells and that learning is the process of creating those patterns of connections, as networks. There is general agreement on a two-stage model for how this happens (e.g. Willingham, 2009; Deans for Impact, 2015). First, information from the senses, together with prior knowledge (memories), is held and processed by ‘working memory’. For example, when exploring a collection of materials, we will be both observing and manipulating the objects, providing sensory information, while also bringing to mind prior knowledge of the materials, such as the names of the objects or the last time that we saw something similar. We experience this as conscious thought. Working memory isn't a box in the brain, it is the simultaneous short-term firing of lots of brain cells, creating a temporary network in which prior knowledge is held together with new information. This firing of brain cells takes energy. The second stage is the consolidation of that pattern of connections as a long-term memory (sometimes called encoding). (For more on this, see the clear accounts by cognitive scientists such as Furst, 2019, or Weinstein and Sumeracki, 2018). As teachers know well, achieving that second stage can take many reactivations of the pattern!

Working memory has a limited capacity: it can be overloaded if there is too much information to process at once (Sweller, 1988; Willingham, 2009). If working memory is overloaded, then information cannot be encoded into longer-lasting memories and 'schemas' (knowledge structures in long-term memory). The implication of this is that 'cognitive load' needs to be managed to support learners, especially when engaging with new information that they may not link together into 'chunks' (Sweller, 1988, 1994). This matters when lesson planning and teaching; we need to make informed guesses about how much new information the children can hold at once, given their existing ideas, and to avoid additional information that may distract from the learning focus. It also matters for teachers themselves since they are needing to make real-time assessment judgments in the busy classroom. We can only hold so much information in the mind at once, so we need to decide what we are looking for and focus our attention.

The TAPS Focused Assessment approach (McMahon, 2018) proposes that, when teaching 'working scientifically', one part of the science enquiry within the context of a whole investigation can be selected as the focus for teacher observation and any recording done by the children. For example, when dropping balls in sand to mimic moon crater formation, recording accurate results might be the focus, while when investigating the waterproofness of different materials, the focus may be on drawing conclusions. Selecting such a focus was previously described in terms of 'manageability', but cognitive load provides a means of explaining the mechanism for this successful intervention. Clarity in the focus of the lesson helps to manage the cognitive load of a science investigation, for both the children and the teacher, while maintaining the holistic context of a purposeful enquiry. Recognising that teacher attention is limited and that we cannot take notice of all children at all times, we devised Focused Assessment lesson plans to help to scaffold the lesson and manage the cognitive load of the teacher, so that they are able to gather useful information about what the children know and can do. This information can then be used formatively to adapt future teaching to support the development of disciplinary knowledge in scientific enquiry (Earle, 2021).

RETRIEVAL PRACTICE

Retrieval practice is bringing information to mind from memory. This is sometimes called the ‘testing effect’, and having regular low-stakes tasks has become well embedded into classroom practice (EEF, 2021). However, although they should not be too stressful, the tasks should not be too easy; it is the effort involved in the retrieval process that helps to consolidate it as a long-term memory. Furst (2019) explains that bringing the information to mind takes deliberate effort, as we reactivate a sequence of neural networks and reconstruct the pathway to the stored information. This reactivation strengthens the pathways, helping to provide a fluency of ideas or an automaticity. This is important because it frees up working memory space for further thinking. For example, once we know the names of materials or parts of a plant, we do not need to work hard to remember them; we can move on to thinking about the purposes or uses of such things.

Traditionally in primary science, we talk about eliciting children’s ideas, which is particularly important because children work hard to understand the world around them before they encounter the relevant science topics in schools, building common-sense explanations for phenomena that may not match the accepted scientific view. To support children’s learning, teachers need to find out about such misconceptions or alternative frameworks, to help to plan and adapt their teaching of substantive knowledge. Such elicitation can also be a form of retrieval for the child, as they bring to mind their previous ideas. People have sometimes been concerned that eliciting children’s existing ideas might actually reinforce misconceptions, and this could indeed happen – for example, if children repeatedly describe the sun moving rather than the Earth turning. If ideas are not in line with the science, then new connections have to be made that help children to recognise the limitations of their current ideas and build new ones that they can turn to instead. The EEF's Stop and Think project is testing an approach based on the premise that children may need to suppress their first response, which is more likely to be based on 'everyday thinking', and activate a more scientific response (Bell et al., 2021).

At the moment, retrieval practice in many schools is about recall. For example, at the start of a science lesson a teacher might say, 'Let's recap last week's plant diagram – what did we call these parts of the plant?' This form of retrieval is good for supporting automaticity: quick and secure recall of well-defined knowledge. However, it has limited potential for building more complex, interconnected knowledge or 'schemas'. To support learning, further time is needed for elaboration, as plants need to be explored in a range of ways, looking at different species and habitats. A stylised flower for labelling looks quite different to most of the garden flowers in the locality and beyond. Utilising elaboration strategies, such as contrasting a daisy and a buttercup, and looking at a wider range of flowering plants, such as grasses and trees, can support deeper and more interconnected learning taking place (McMahon et al., 2021).

The TAPS project resources include a range of examples for different topics and year groups that can be used to develop retrieval practice into a wider repertoire of strategies to challenge children to extend ideas as well as recall knowledge. For example, an activity where items are sorted into 'living' and 'non-living' can provoke thoughtful discussions around the features of the groups and may lead on to consideration about whether a further group should be added, such as 'used to be alive'. Such discussions elicit children's ideas, but they also provoke the making of connections with other ideas, and this elaboration strengthens meaning-making (Furst, 2019). This is important because it opens up possibilities for making connections between school science and children's broader social and cultural experiences, and in so doing, helps children to see science as relevant for them (Archer et al., 2015). However, we do need to hold in mind Perry et al.'s (EEF, 2021) point that elaboration and self-explanation may improve learning but may also risk imposing a higher cognitive load or producing misconceptions. Teachers' professional judgments about when to use more simple retrieval and when to move to more elaborate forms of retrieval will be informed by the stage within the topic and judgements about the needs of the children at that point in time. For example, once young children are more confidently categorising plants as living things, trickier items could be discussed, such as a dormant seed or seaweed that has washed up on the beach. The decision to move beyond simple retrieval to elaboration is a professionally situated judgement and one that may involve some to-ing and fro-ing within the moment, as teachers support children to discuss their scientific ideas.

CONCLUSIONS

Cognitive science provides useful ways for thinking about learning from the perspective of the learner: the focus is on the learner as an individual. However, there is also a large body of educational research that considers learning within the context of a dynamic classroom – for example, from a social constructivist perspective. Each different perspective provides valuable insights. For instance, cognitive science has been influential in TAPS in helping to recognise the value of eliciting children's ideas in order to consolidate them, as well as to enable the teacher to assess their starting points in relation to the curriculum. It also provided the language of cognitive load to help to explain what makes an assessment 'manageable' for teachers assessing learning outcomes within the context of a practical primary science investigation. Considering the social/cultural dimensions alongside the cognitive helps to recognise the complex professional role of the teacher in using formative assessment in a whole-class situation. We suggest that it is useful for cognitive science insights to be considered in relation to other educational research, in order to support the development of understanding about teaching and learning processes in complex systems like classrooms and schools.

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