Building knowledge and understanding

What happens in the brain when a student grasps a new idea for the very first time—and what does this mean for teaching?

Author/s:

Paul Howard-Jones
Professor, Graduate School of Education, University of Bristol, United Kingdom

Theme/s:

Effective lifelong learning / Early childhood development / Learning how to learn / Sleep and learning

This report arises from Science of Learning Fellowships funded by the International Brain Research Organization (IBRO) in partnership with the International Bureau of Education (IBE) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IBRO/IBE-UNESCO Science of Learning Fellowship aims to support and translate key neuroscience research on learning and the brain to educators, policy makers, and governments.

Executive summary

- ***Being aware of students' prior knowledge is important*** for a teacher because this is the foundation on which the students' new knowledge will build.
- Teachers help students think meaningfully about new ideas by ***encouraging students to make connections with their prior knowledge***. This is particularly important for children, whose neural circuitry for this connection-making process is still developing. Differences in learning and development will result in diverse individual differences within any class.
- The brain is multisensory. ***Clear, concise instruction using all the senses*** aids communication and understanding of new knowledge, encouraging students to make links between different representations.
- Our *mirror neuron system* helps us read each other's minds. ***Gestures and faces communicate knowledge and emotions, both consciously and unconsciously***, supporting the teacher's transmission of concepts, confidence, and enthusiasm.

Building student knowledge requires two-way communication between teacher and student

Effective teaching and learning can be considered to involve:

- *engagement* of the learner's attention
- teacher-guided *building* of knowledge and understanding
- *consolidation* of learning through application, practice, and reflection.

Helping students grasp new concepts requires a two-way flow of information, including clear communication by the teacher of concepts, but also communication by the student of what they are beginning to know or know already (through their questions, answers, homework, classwork, etc.). This prior knowledge is the foundation on which any future learning will be built.

New knowledge builds on prior knowledge

To have meaningful thought processes about new ideas, students must build upon whatever prior knowledge they already possess. To ensure a student's readiness to learn new material, effective teachers gain an awareness of their students' prior knowledge through various means. They note their students' responses to questions in class and reflect on the questions their students ask themselves, as well as on students' responses to classroom tests and homework, and many other types of formative assessment. However, a teacher's role here goes beyond *just* ensuring the student has the required prior knowledge before progressing to the next stage.

Figure 1 shows two key regions in the brain for knowledge construction. These are the medial prefrontal cortex (PFC), which helps to detect the fit of incoming knowledge with what is already known and to retrieve this prior knowledge, and the lateral PFC for the processes of connecting new incoming knowledge with this prior knowledge[1].

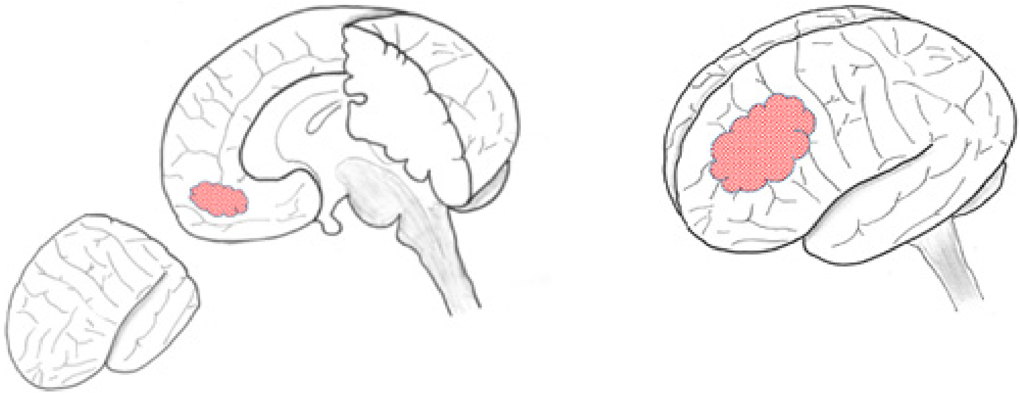

Figure 1. Schematic indication of the two key regions in the brain for knowledge construction: the medial prefrontal cortex (left) and lateral prefrontal cortex (right).

In schoolchildren, these regions (and particularly lateral PFC) are known to be relatively immature[2], which seems to disadvantage them in using prior knowledge even when they possess it[3]. Therefore, it is important that children are prompted to reactivate appropriate prior knowledge (e.g., revision question and answer) before new information is presented and then encouraged to make connections between the new information and their existing knowledge. A connection between a new concept and what has been taught before may seem obvious to an adult teacher, but perhaps not to a child whose frontal cortex is still developing.

Clear, concise instruction and multisensory experience

Effective teachers communicate clearly and concisely, with little unnecessary information. Our ability to maintain information in our attention is limited, and distracting or irrelevant information can disrupt our efforts to process learning content. For example, visual distraction tends to interfere with connectivity of brain networks guiding memory retrieval, reducing our ability to recall previously learnt visual information[4].

However, the additional information provided by multisensory experience can be helpful. Scientists have begun to understand that the brain is organized in a more multisensory way than previously imagined[5]. Consideration of how to use the different senses when communicating is important here. Careful use of modalities (e.g., auditory and visual) can support learning by encouraging students to link different representations of a concept[6]. Rather than just using multiple senses as much as possible, the potential of multisensory experience relies on students connecting between these different forms.

The importance of this linking also applies to using concrete and abstract representations in the classroom (see, for example, Figure 2). When a teacher introduces a concept to children using a concrete example, the children find it easier to reason about the concept—but only in respect of this physical example. They can find it difficult to move beyond the particular concrete example provided. However, when a concept gets introduced in an abstract way (say, using symbols or drawings), children first find it more difficult to grasp. This is because the children must link their own concrete experience to the abstract representation to make sense of it. However, once grasped, this abstract representation travels in a way that the concrete example does not. Being shown a concept using an abstract representation like a diagram helps the learner transfer the new knowledge to new contexts. Teachers are now recommended to use a "concreteness fading" approach in which the teacher moves gradually from the concrete to the abstract, supporting the students in making links between these different representations.[7]

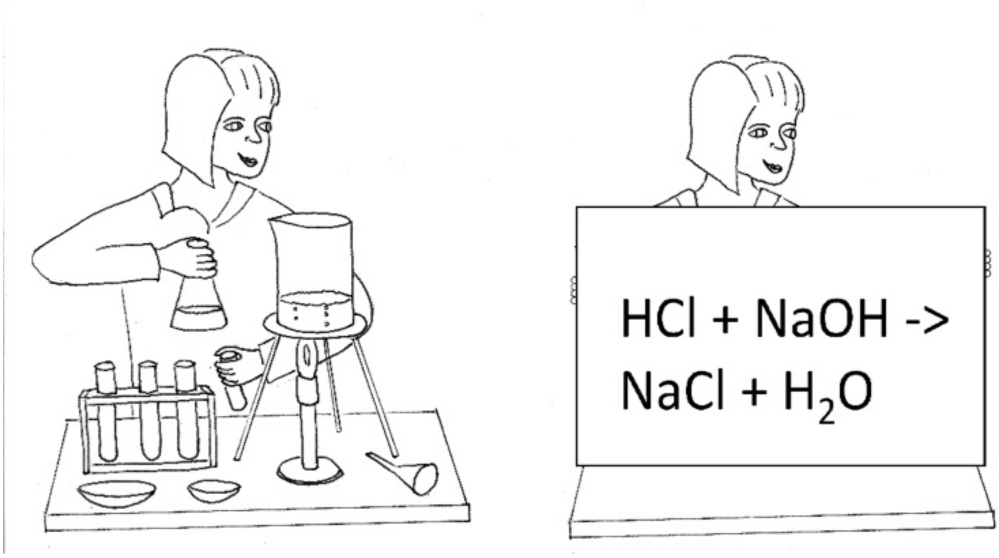

Figure 2. A teacher can introduce a concept to children using a concrete example (left) or using abstract representation (right). There are advantages to both approaches, but the important thing is for children to be able to make the connections between them.

Unthoughtful attempts to present information in a multisensory way can easily go wrong. Reading text and listening to speech might be thought of as essentially visual and auditory forms of communication, but reading employs much of the circuitry we use for understanding speech[8]. This means that presenting verbal explanations alongside a lot of text (e.g., on a PowerPoint slide) is similar to asking the learner to process two explanations simultaneously—making it difficult to understand either[9].

Embodiment and movement

Throughout evolution, transforming incoming sensory information into action has been a fundamental organizing principle for the brain. This helps us understand why acting out ideas helps us understand and learn them. In a recent study, for example, students' understanding of angular momentum increased (with consequently higher test scores) when they were encouraged to physically explore the idea with the help of bicycle wheels. Brain imaging showed their improved performance could be explained by additional activation of sensorimotor brain regions when students were acting out their reasoning about angular momentum[10].

We also communicate with our bodies (i.e., our gestures and facial expressions)—although often without realizing it. We activate particular brain regions when we make a gesture but, surprisingly perhaps, this activates some of the same regions in the brain of anyone who observes us[11,12]. This so-called mirror neuron system is thought to help learning through imitation and may also help transmit attitudes and emotional responses. Observing an emotion in someone else (e.g., through their expression) activates brain mechanisms involved with experiencing similar emotions[13-15.]

Therefore, the unconscious workings of our brains can help explain how easily negative emotions, such as anxiety about mathematics, can be transmitted from teacher to student[16], and how positive teacher attitudes can become linked to higher student achievement (see, for example, Ref. [17]). More positively, the mirror neuron system may also unconsciously help the teacher transmit concepts, confidence, and enthusiasm.

References

1. Brod, G., Lindenberger, U., Werkle-Bergner, M. & Shing, Y. L. Differences in the neural signature of remembering schema-congruent and schema-incongruent events. *Neuroimage* 117, 358-366, doi:10.1016/j.neuroimage.2015.05.086 (2015).

2. Brod, G., Werkle-Bergner, M. & Shing, Y. L. The influence of prior knowledge on memory: A developmental cognitive neuroscience perspective. *Front. Behav. Neurosci.* 7, 13, doi:10.3389/fnbeh.2013.00139 (2013).

3. Shing, Y. L. & Brod, G. Effects of prior knowledge on memory: Implications for education. *Mind, Brain, and Education* 10,

153-161, doi:10.1111/mbe.12110 (2016).

4. Wais, P. E. & Gazzaley, A. Distractibility during retrieval of long-term memory: Domain-general interference, neural networks and increased susceptibility in normal aging. *Frontiers in Psychology* 5, 12, doi:10.3389/fpsyg.2014.00280 (2014).
5. Quak, M., London, R. E. & Talsma, D. A multisensory perspective of working memory. *Front. Hum. Neurosci.* 9, 11, doi:10.3389/fnhum.2015.00197 (2015).
6. Mayer, R. E. & Anderson, R. B. Animations need narrations – an experimental test of a dual-coding hypothesis. *Journal of Educational Psychology* 83, 484-490, doi:10.1037//0022-0663.83.4.484 (1991).
7. McNeil, N. M. & Fyfe, E. R. "Concreteness fading" promotes transfer of mathematical knowledge. *Learning and Instruction* 22, 440-448, doi:10.1016/j.learninstruc.2012.05.001 (2012).
8. Buchweitz, A., Mason, R. A., Tomitch, L. M. B. & Just, M. A. Brain activation for reading and listening comprehension: An fMRI study of modality effects and individual differences in language comprehension. *Psychology & neuroscience* 2, 111-123 (2009).
9. Horvath, J. C. The neuroscience of PowerPoint (TM). *Mind, Brain, and Education* 8, 137-143, doi:10.1111/mbe.12052 (2014).
10. Kontra, C., Lyons, D. J., Fischer, S. M. & Beilock, S. L. Physical experience enhances science learning. *Psychological Science* 26, 737-749, doi:10.1177/0956797615569355 (2015).
11. Rizzolatti, G. & Craighero, L. The mirror neuron system. *Annual Review of Neuroscience* 27, 169-192 (2004).
12. Filimon, F., Nelson, J. D., Hagler, D. J. & Sereno, M. I. Human cortical representations for reaching: Mirror neurons for execution, observation, and imagery. *NeuroImage* 37, 1315-1328, doi:http://dx.doi.org/10.1016/j.neuroimage.2007.06.008 (2007).
13. Gallese, V. The roots of empathy: The shared manifold hypothesis and the neural basis of intersubjectivity. *Psychopathology* 36, 171-180, doi:10.1159/000072786 (2003).
14. Gallese, V., Eagle, M. N. & Migone, P. Intentional attunement: Mirror neurons and the neural underpinnings of interpersonal relations. *J. Am. Psychoanal. Assoc.* 55, 131-176 (2007).
15. Wicker, B. *et al.* Both of us disgusted in My insula: The common neural basis of seeing and feeling disgust. *Neuron* 40, 655-664, doi:http://dx.doi.org/10.1016/S0896-6273(03)00679-2 (2003).
16. Beilock, S. L., Gunderson, E. A., Ramirez, G. & Levine, S. C. Female teachers' math anxiety affects girls' math achievement. *Proc. Natl. Acad. Sci. U. S. A.* 107, 1860-1863, doi:10.1073/pnas.0910967107 (2010).
17. Ker, H. W. The impacts of student-, teacher- and school-level factors on mathematics achievement: An exploratory comparative investigation of Singaporean students and the USA students. *Educational Psychology* 36, 254-276, doi:10.1080/01443410.2015.1026801 (2016).