Key Ideas from the Literature:
Prior Knowledge and Conceptual Change

3 Conditions and 3 Grain Sizes of Knowledge

When thinking about learners' prior knowledge, skills, beliefs, and concepts, consider **three conditions** (*1*):

1. ***Missing.*** A learner may have no prior knowledge of the concepts to be learned, although he or she may have some related knowledge. If prior knowledge is missing, learning will need to consist of adding new knowledge.

2. ***Incomplete.*** A learner may have some correct prior knowledge about the concepts to be learned, but that correct knowledge is incomplete. In this case, learning can be conceived as filling in the gaps.

3. ***Misconceived.*** A learner may have acquired prior ideas, e.g., from school or everyday experiences, that conflict with the concepts to be learned. In this case, learning will entail changing prior misconceived knowledge to accurate knowledge.

When thinking about prior knowledge that is misconceived, think about knowledge in **three grain sizes** (*1*):

1. ***Individual belief*** refers to a single idea or piece of information. For example:
   > A learner believes that all blood vessels have valves or that the heart is responsible for re-oxygenating blood. These beliefs are misconceived; they are considered false beliefs.

   Sometimes, explicitly or implicitly confronting the false belief with correct information that contradicts and refutes the false belief is sufficient to achieve conceptual change. The false belief can be *revised*.

2. A ***mental model*** is formed from an organized collection of individual beliefs. It's an internal representation of a concept, or an interrelated system of concepts, that corresponds in some ways to the external structure that it represents (*2, 3*).
   a. Learners may have missing, incomplete, or misconceived mental models. For example:
      > A learner has no mental model for (no understanding of) the circulatory system, or else builds a mental model of circulation as a single-loop system, in which the heart is the source of oxygenated blood.

      The learner's model is in conflict with the normative scientific view, but coherent in the sense that he can apply his mental model to arrive at similar (and consistently incorrect) explanations and predictions for a variety of questions.

b. Sometimes, when false beliefs within a flawed model are refuted by instruction and recognized by learners as contradictions, the learners can "self-repair" their flawed mental models (*1*). The flawed mental models can be *transformed* into the correct model. But knowing and learning many correct individual beliefs, or revising many false individual beliefs, doesn't guarantee successful transformation of a flawed mental model into the correct one. Critical individual false beliefs can undermine a correct mental model. For example:

   In understanding what causes moon phases, we saw that a common and critical false belief among learners is that Earth's shadow causes the phases of the Moon.

   To counter the false belief's role in the mental model, in our moon phases routine we deliberately explored shadows at the very start of the activity.

3. ***Categorizing*** is the process of identifying a new concept and assigning it to a known category to which you feel it belongs (*4*). We typically categorize everything we encounter, automatically—whether consciously or not (*5*). This process is an important learning mechanism, because in assigning a concept into a category, the concept inherits the features and attributes of that category. As a result, a learner can use knowledge of the category to make many inferences and attributions about the new concept, object, experience, or phenomenon.
   a. Categories can be organized by their properties and the relations between them, such as whether they are **entities** (e.g., can be contained, have weight, occupy space); **processes** (e.g., occur, take time); or **mental states** (e.g., emotion, intention).

   b. Learners may have misconceptions because they have mis-categorized something in one of two ways:
      - They may mis-categorize something *into one category rather than another*.
        For example, learners often mis-categorize heat as an *entity*. They think of heat as a physical object, such as "hot molecules," or a substance, such as "hot stuff" or "hotness" (*6*). But heat is actually a *process*, not an entity: it's the transfer of energy from a hot object to a colder object.
      - Or learners may mis-categorize something *within a category*. For example:
        Children who believe Earth is flat categorize it as a *physical* entity, while those who believe it is spherical categorize it as a *solar* entity in space (*7*).

   If a learner's misconception is due to an error in categorizing, then instruction needs to focus at the categorical grain-size level.

Addressing Misconceptions

(A) Instructional approaches to building learners' conceptual understanding, which include addressing their misconceptions, need to consider how the misconception is occurring for the learners. Learners sometimes let go of their incorrect ideas readily. At other times, the misconceived understandings are robust and highly resistant to change, despite instructional interventions. Researchers and educators are still challenged with understanding why conceptual change can be so difficult.

Studies in cognitive neuroscience offers some interesting insights (*8, 9*). Functional MRI (fMRI) scans of students engaged in causal reasoning tasks showed that when students were given data consistent with their preferred theory, areas in the brain thought to be involved in learning were activated. When presented with data *in*consistent with their preferred theory, areas of the brain associated with error detection and conflict monitoring were activated.

Essentially, when people receive information inconsistent with their preferred theory, learning does not easily occur. So, what are the origins of their erroneous thinking?

(B) Learners' inaccuracies arise in many different ways:

- ***Personal experience***. Learners' misconceptions often arise from their experiences—that a heavy rock falls to the ground faster than a light piece of paper, or that it's hotter as they move closer to the fire. These observations support and strengthen their beliefs—that heavy things fall faster than light things (versus the physicist's view that all objects fall at the same rate), or that Earth is closer to the Sun (and therefore hotter) during summer (versus the astronomer's explanation that seasons are due to the tilt of Earth's axis in relation to the Sun). So while their everyday observations are sensible and useable for explaining many experiences, they can also be problematic.
- ***Instruction***. Students may overgeneralize analogies, particularly if they're unfamiliar with a topic or don't understand the source example (*10*) or can't discriminate between good and faulty sources. The teaching materials may be inaccurate or misleading; science content in textbooks has been found to give erroneous explanations and incomplete information (*11, 12*), or the diagrams may be depicted in confusing and misleading ways. (For example, a nucleus is drawn large and the electron very small, with no indication in the text to clarify the scale representation; students are then surprised to learn that the nuclei themselves are very small, even the most massive ones (*11*).)
- ***Diversity of information***. Topics like climate change, evolution, smoking, and vaccines have social, political, and economic implications. For some topics, such as climate change, the scientific concepts are complex and sometimes

counterintuitive to personal experiences. For others, such as evolution, information is influenced by different belief systems. Moreover, the concepts may not be taught in schools at all, or what is taught competes with other, contradictory sources of information (*13*).

(C) Conceptual change does happen. It takes time and is a slow process. Conditions that facilitate conceptual change include:

- ***Awareness of contradiction***. In order for learners to revise their false beliefs, transform their mental models, or even re-categorize concepts, they must recognize the contradiction between what they think and the scientific view (*1, 14*). Without this awareness, learners may simply assimilate the new information without clarifying for themselves how it fits, or they may ignore the new information altogether.
- ***Availability of alternative concept***. Learners may revise a belief if he can think of (or is given) an alternative belief. If no alternative theory, model, or interpretation is available, he may stick to the old belief even when predictions from it are not supported (*14*).

(D) Instructional practices found to be especially effective in addressing learners' misconceptions include (*15*):

- Student participation, active engagement, and discourse
- Opportunities for reflection, metacognition *(16)*
- Interactive lecture, lecture tutorial *(17–19)*
- Bridging analogies *(10, 20)*

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