What do the modern sciences of the mind tell us about how we come to understand scientific concepts? – T. Amin and J. Haglund (Workshop Session 3)

Extended Abstract

Our contribution to this session will be to outline some of the "big ideas" from the fields of science education, developmental psychology and cognitive science that we find are particularly relevant to characterizing how scientific concepts are understood and how this understanding develops. Research in science education has taught us that lay conceptual understanding both interferes with and supports learners' attempts to understand scientific concepts. A lot of research since the 1970's has been describing what learners' lay understanding of scientific concepts is before they begin formal instruction. Misunderstandings were often found to persist despite extended periods of formal instruction. Researchers set about describing pre-instruction concepts and compared them to scientific concepts as a way to diagnose the learning challenge. They have also identified how lay intuitions can be very useful when drawn on strategically to help learners understand scientific concepts. Two broadly distinct perspectives have emerged: the first describes concepts (including lay concepts) as parts of networks of concepts and the process of change as one of theory transformation; the second sees lay conceptions as consisting of disorganized knowledge fragments and view the process of change as a process of organizing existing fragments of knowledge. These perspectives are often contrasted in terms of the extent to which they emphasize discontinuity between lay and scientific understanding (the theory transformation perspective) as opposed to continuity (the fragmentation, or "knowledge-in-pieces" perspective). The too perspectives have been converging in recent year and we believe that elements of both perspectives are needed for an accurate account of concept learning in science.

Research on conceptual development in developmental psychology has taken place in parallel to the science education research just mentioned. Some developmental psychologists have themselves tackled the problem of concept learning in science using ideas from developmental psychology. A particularly important contribution has been diagnosing the nature of the learning challenge by characterizing more precisely what lay concepts are like and how these are shaped by ideas formed in early childhood and, indeed, in infancy. Moreover, this foundational research has proposed various mechanisms of change. First, it is claimed that abstract (possibly innate) concepts guide concept learning in the early years. Knowledge in core domains such as those of inanimate objects, animate agents, number and space has been researched and it has been suggested that there is a degree of continuity in a human being's conceptual life that can be attributed to these core domains. Second, noticing patterns in sensorimotor experience leads to the construction of generalizations over these experiences, referred to as image-schemas – e.g. *containment*, *possession*, *exchange of possession*, *movement along a path*. These image-schemas play a role in the formation of concepts in early childhood. Third, the growth of conceptual knowledge in particular domains – for example, knowledge of the material world or living things - is influenced by growth in our ability to *reflect on* knowledge, so called 'metacognition,' and on the growth of representational resources, most importantly language. It is suggested that the language-based

mechanism of creative bootstrapping enables the construction of novel concepts and explains discontinuities in conceptual development.

From cognitive science we have selected two lines of research that are important to mention: research on the difference between experts and novices; and research on the representation of concepts. Research on the acquisition of expertise initially proposed an account of concept change highlighting the reclassification of concepts from one ontological category to another. For example, learning the scientific concept of heat was said to involve reclassifying heat from the category of substance to the category of (constraint-based) process. But research on the representation of concepts in cognitive linguistics and cognitive psychology has suggested that even abstract concepts are represented in terms of image-schematic structures (sometimes referred to as perceptual symbols). The pervasive use of metaphor implicitly in language (the phenomenon of conceptual metaphor) was the initial source of evidence for this claim. Patterns of metaphorical mapping such as TIME IS A MOVING OBJECT (e.g. *We are gradually approaching the end of the year*) and STATES ARE CONTAINERS (e.g. *I fell into a deep depression*) suggested that abstract concepts are represented metaphorically in terms of image-schemas such as *moving objects* and *containment*. Research applying this perspective to scientific thinking has revealed subtle, yet pervasive metaphorical construals of abstract concepts in scientific writing and problem solving. The same concept can be flexibly construed in terms of multiple metaphors. Our research in this area has convinced us that the ontological shift view was too static and simplistic and that the acquisition of expertise involves learning to coordinate multiple metaphors in strategic ways for particular purposes. A narrative mode of thought is one example of how metaphors are coordinated in the context of scientific thinking. We illustrate this with an episode of problem-solving involving the concept of entropy.

Overall, the picture that emerges is that both lay and scientific concepts are complex knowledge systems and that developing an understanding of a scientific concept involves incorporating new knowledge elements of multiple formats (e.g. image-schematic and linguistic) and reorganizing the knowledge system as a whole. Both continuity and discontinuity need to be acknowledged. To see continuity we have to identify image-schematic knowledge structures and concepts present very early in life, possibly at birth. To see discontinuity we have to describe the dramatic reorganizations that often need to occur as scientific expertise is acquired; these often involve the appropriation of specific forms of discourse, of which narrative is one example.