MOLECULAR CONCEPTIONS OF RESEARCH INTO LEARNING

Keith S. Taber
University of Cambridge Faculty of Education
Cambridge
England, UK
kst24@cam.ac.uk

Synonyms

Contingent learning and science teaching research programme; Research into cognitive mechanisms of learning; Research into learning informed by information-processing models of cognition; Fine-grained constructivism; Inclusive model of cognition and conceptual development.

Definition

Alternative conceptions and alternative conceptual frameworks are labels that may be used to describe the inferred conceptual structures related to specific concepts (e.g. energy, force, etc) represented in students' memories, which are accessed and applied in cognition. These terms may be variously used to describe both the learners' mental structures themselves and the models researchers construct to represent common features of such structures across samples of learners.

Constructivism: Here constructivism is used to mean a perspective that considers learning to be iterative and accumulative, so that new learning is constrained and channelled by the way existing understanding provides the interpretive basis for making sense of new information (such as instruction).

Contingent learning research programme: A perspective on learning as being highly contingent. What is learned in a teaching situation is constrained and channeled by how new information is understood in terms of its context (e.g. including linguistic features, social context of learning, pedagogic sequences and models used etc) being interpreted by the available cognitive apparatus (e.g. constrained by working memory capacity) through those aspects of a learner's existing conceptual structures - in terms of prior understanding of concepts, epistemological commitments (such as understanding the role and nature of a teaching model or representation) - which are cued in that specific learning episode.

Folk knowledge: Technically suspect ideas that have common currency in the life-world. So the common folk model of teaching is of transferring knowledge into students' heads, whereas a constructivist perspective considers that individuals must actively construct their knowledge of the world.

Information-processing perspective: a way of modelling cognition in terms of how information is inputted, processed, stored etc, within the learner as a 'system'

Kuhnian paradigm-shift: Thomas Kuhn's notion of how some 'revolutionary' changes in science involve discontinuous shifts between different set of fundamental commitments. So for example, studies of academic learning that focus on conceptual development in terms of specific prior understandings of topic areas may be seen to derive from a different paradigm than (i.e. be incommensurable with) those which focus on the domain-general cognitive structures available to support learning.

Learning impediments: If teaching for conceptual learning is understood to be based on the teacher attempting to communicate information that the learner will understand (as intended) in terms of their existing conceptual structures, then there are a range of potential ways the teaching-learning system can break down. One ‘typology of learning impediments’ includes: missing pre-requisite knowledge (deficiency learning impediments); failure to recognise the connection with intended target prior knowledge (fragmentation learning impediments); interpreting new information in terms of existing alternative conceptions (grounded learning impediments); and creatively forming unintended and inappropriate links with existing knowledge (associative learning impediments). The idea of learning impediments draws upon the philosopher Gaston Bachelard’s ‘epistemological obstacles’.

Research programmes: The philosopher Imre Lakatos explained the progress of science in terms of coherent research ‘programmes’ which were built upon stable sets of hard-core assumptions, and guided by heuristic rules for developing the programme. Lakatos’s model offers guidance on evaluating research programmes, and explains how apparent anomalies can be tolerated within a programme without indicating the need for a Kuhnian paradigm-shift.

Theoretical Background

The notion of molecular and molar conceptions of learning derives from the field of science education (and draws on a chemical analogy), but is more widely applicable – certainly to learning of conceptual material across academic contexts. The context for the construct being proposed was a shift (around 1980) in the focus of much research into science learning from a cognitive to a conceptual frame (constructivism in science education) and subsequent criticisms of this shift. The suggestion (Taber, 2000) was that the constructivist research programme (described below) should be re-conceptualised as adopting complementary foci where research exploring cognitive mechanisms (e.g. information processing approaches) would inform and be informed by studies of developing thinking and understanding in specific concept areas.

The labels of ‘molecular’ and ‘molar’ conceptions of learning derived from chemistry, a science that has progressed by the simultaneous study of the behaviour of substances at the laboratory bench (the molar level) and development of theoretical models to explain bench phenomena in terms of the properties and behaviour of conjectured submicroscopic entities (the molecular level). So just as chemical reactions may be understood in terms of processes involving atoms, molecules and electrons, it was argued that the shifts in students’ conceptual structures needed to be understood in terms of the cognitive processes by which conceptions are formed, integrated into larger structures, modified through further study, accessed from memory and applied, etc. As in chemistry, neither the molar nor the molecular level of analysis can by itself offer a full account of the phenomena: that is offer an account of student learning sufficient to inform effective pedagogy. The argument was therefore that these different studies could be seen to form part of a single coherent research programme, later characterised in terms of the model of scientific (‘progressive’) research programmes developed by Imre Lakatos (Taber, 2006). This evolving programme retained the tenets of the alternative conceptions movement (see below), but incorporated them within work aiming towards a more comprehensive account of student conceptual development (see Figure).

There has been a vast research effort to explore student thinking and learning in science subjects, mainly at school and college levels, in view of the wide recognition of the extent of learning difficulties in the sciences. Such problems have been of major concern within education for some decades. In the US, cold-war paranoia in the wake of the USSR launching Sputnik highlighted the perceived failures of science education there. In the UK, the Nuffield curriculum development projects from the 1960s led a trend towards science teaching with a much greater focus upon concepts. As science is largely about developing conceptual models and theories, this led to a more authentic science education; if also more challenging learning for students.

Indeed it became clear that many students struggled to acquire an acceptable level of understanding of the content presented in the science curriculum, raising the question of whether such a concept-based science education was suitable for all learners at secondary (high school) levels. Such concerns were often related to the Piagetian model of cognitive development, as many of the science concepts being taught at upper secondary (senior high school) level would from a Piagetian perspective seem to require well-developed formal operational thought, whereas surveys suggested that many students in the target age range would not have fully reached this stage of cognitive development. Indeed, as many of the concepts that are taught at this level are of the form of abstract models of limited ranges of application, which are often used alongside other logically inconsistent models (for example, models of the atom as having discrete shells of electrons or having clouds of 'electron density' which must be understood probabilistically), it could be argued that attainment of formal operational thought may not be sufficient to ensure effective learning of target knowledge. Perry's studies showing that undergraduate students entering elite colleges generally had limited ability to deal with complex contexts that did not definitive conclusions may be of some relevance in this context.

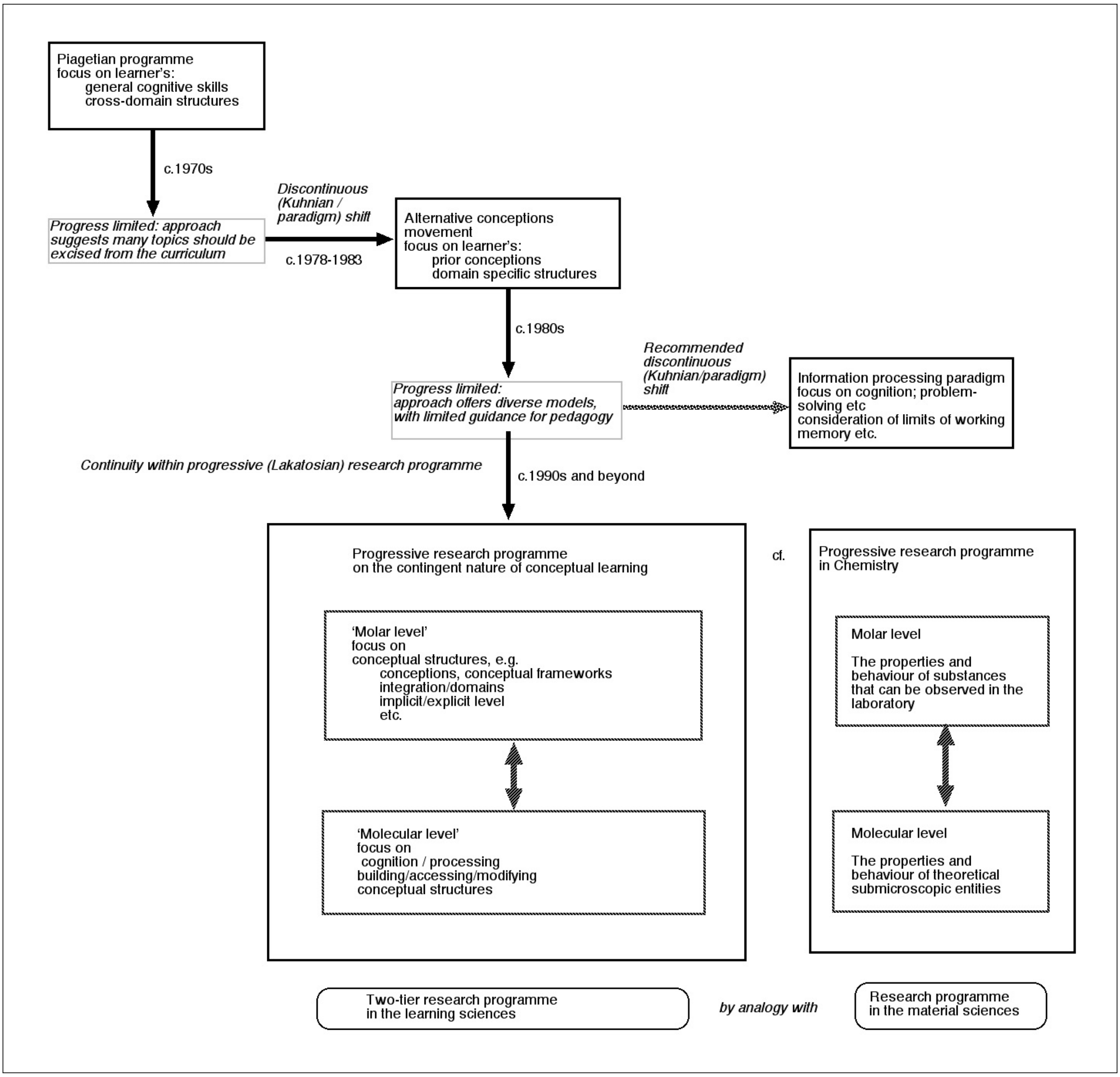

Figure: A schematic representation of the evolution of the research programme into conceptual learning in science, and the analogy with the science of chemistry.

Within the science education research community, the major response to this situation was to shift the focus from the cognitive aspects of students' learning difficulties (i.e. in terms of broad constructs such as Piagetian levels, and domain-general structures of cognitive operations supporting learning), to the conceptual (i.e. in terms of how students understood specific science concepts such as force, energy, plant nutrition etc). This can be understood as a Kuhnian paradigm-shift to a completely new basis for guiding research in the field (Driver & Erickson, 1983; Gilbert & Watts, 1983).

The key descriptor for the new paradigm was 'constructivism', which whilst partly developed from the general thrust of Piaget's ideas (for example in the seminal work of Rosalind Driver), was also strongly influenced by the work Ausubel, Bruner, Vygotsky, and - through the work of the *Personal Construction of Knowledge Group* at Surrey University, UK (John Gilbert, Maureen Pope, Mike Watts and colleagues) - the personal construct psychology of George Kelly. The research programme was also known as the 'alternative conceptions movement'.

Constructivist researchers around the world (led by those in Waikato, Aeotora/NZ and Leeds, England) started exploring in detail the nature of students' thinking about science topics on the basis that any new learning would involve teaching being interpreted in terms of existing conceptual frameworks. This work was often carried out from an approach informed by ethnographic or phenomenological perspectives, reflected in how many researchers labelled their findings as intuitive theories, alternative conceptions or alternative conceptual frameworks. However, in discussing work with teachers, the elicited ideas were often referred to as 'misconceptions', which was unfortunately sometimes interpreted as simple misunderstandings that could be readily 'corrected' through clarification by teachers. However, research showed that some of the ideas students held could be very tenacious, and were not readily modified by teaching.

Over a period of several decades, researchers have uncovered a vast catalogue of alternative conceptions in most science topics, across a wide range of ages, and in various educational contexts. It is now widely accepted that science teaching should be informed by knowledge of the personal conceptions that students bring to class. The research has not just set out to catalogue students' ideas, but also to characterise the nature of, and the best teaching responses to, the different alternative ideas found.

Consider examples of common alternative conceptions from the main areas of school science (Taber, 2009):-

Biology: Plants grow by taking in new material through their roots (where in school science students learn that much of the material in plants is acquired from the air by photosynthesis);

Chemistry: Chemical reactions occur to allow atoms to obtain full outer shells of electrons (whereas in most reactions children learn about in school, the reactant species already meet this criterion);

Earth science/astronomy: It is warmer in the summer because the Earth's orbit takes it closer to the Sun at this time of year (ignoring how the Northern and Southern hemispheres experience summer at opposite points in the orbit);

Physics: A force is required to keep an object moving (whereas in school physics students learn an object will continue to move with the same velocity *unless* acted upon by a force).

Despite a good deal of success in building up an understanding of how learners think about science topics, the 'constructivist' research programme has also been subject to a good deal of criticism (Taber, 2009). One area of criticism concerned the nature of learners' conceptions: i.e. that although 'constructivist' researchers often characterised students' alternative conceptions as tenacious, theory-like ideas that the holders were strongly committed to; other workers (e.g. Joan Solomon, Guy Claxton) claimed that ideas elicited from students were often found to be labile, even romanced, and context-dependent with very limited ranges of application. A second major criticism was that whilst research had done much to catalogue student thinking, efforts to set out effective pedagogy had been less successful. One particular argument made here (for example by Alex Johnstone) was that effort spent detailing students' ideas could have been more usefully spent considering the processes by which learning takes place in science, for example in terms of an information-processing perspective.

It was in this context that the notion of 'molecular' and 'molar' conceptions of research into learning science was mooted, reflecting one of the early characterizations of the constructivist programme: the *generative learning model* of Osborne and Wittrock (1985). Encouraging researchers working at these different levels to consider they are part of the same overarching research programme should ensure they: share the same set of basic commitments; consider they are working on a linked and coherent set of problems; and report their work with the concerns and interests of the broad range of researchers in the field in mind. In Kuhn's terms, they would be considered to work within the same paradigm or disciplinary matrix.

The evolving research programme has been described as concerned with exploring the contingent nature of conceptual learning looking to bring together considerations relating to physical intuition, linguistic cues, social influences, effects of teaching and so forth, as well as limitations of the kind raised by Piaget. Such a programme seeks to explain how students develop the range of different types of conceptions.

It would seem the physics example derives directly from the experience of the young child in moving objects around. The astronomy example clearly cannot derive directly from personal experience, but could relate to the intuitive application of a tacit abstracted pattern that 'closer means stronger' constructed from various direct experiences. The biology example may well relate to both the greater salience of soil and fertilizer than air for children; but could also link with folk knowledge descriptions of 'feeding' plants, and an inappropriate analogy with human nutrition. Neither direct experience, nor common folk knowledge, obviously explains how children come to make assumptions about the behaviours of molecules, electrons and atoms seen in the chemistry example. Common teaching approaches seem to comprise a type of learning impediment.

Such an inclusive approach has drawn upon the work of those such as Karmiloff-Smith and diSessa who consider how implicit knowledge is drawn upon in student thinking, as well as more 'traditional' studies in the field characterising the nature, extent, stability, level of integration and coherence, etc. of the conceptual knowledge elicited from students (Taber, 2009).

Important Scientific Research and Open Questions

The contingent learning and science teaching research programme is still quite immature, in that it offers a good deal more description of student conceptions than well-supported accounts of how learning occurs, or how it can better be channeled by effective teaching. A key question is the extent to which the focus should be primarily on the individual learner, rather than the social context of learning. There is also considerable scope for contributions from studies offering rich descriptions of concept learning within specific cultural contexts: it is clear both that there are some strong commonalities in student conceptions across cultures, and that some conceptual development is strongly effected by linguistic patterns or specifics of institutional/educational contexts. Given the range of co-varying factors across diverse educational settings that may influence conceptual learning (and the lack of experimental manipulation possible in most educational studies), there is a considerable challenge in designing research able to unpick some of the complexity at work (Taber, 2009). [1902 words]

Cross-References

Automatic information processing Regular Entry 00494 *85/85*

Cognitive models of learning Regular Entry 00241 *125/125*

Constructivist learning Regular Entry 00142 *157/157*

Folk knowledge and academic learning Regular Entry 00487 *244/244*

Learning in science Regular Entry 00382 *351/351*

Piaget's learning theory Regular Entry 00039 492/492

Science learning Regular Entry 00381 *549/549*

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