education review // reseñas educativas
editors: gene v glass gustavo e. fischman melissa cast-brede

a multi-lingual journal of book reviews

January 4, 2011 Volume 14 Number 1 ISSN 1094-5296

Understanding the Nature and Processes of Conceptual Change: An Essay Review

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Vosniadou, Stella (Ed.) (2008) *International Handbook of Research on Conceptual Change.* NY: Routledge

Pp. xxviii+740 ISBN 978-0-8058-6045-0

Citation: Taber, Keith S. (2011 January 4) Understanding the nature and processes of conceptual change: An essay review. *Education Review, 14*(1). Retrieved [Date] from http://www.edrev.info/essays/v14n1.pdf

With the *International Handbook of Research on Conceptual Change*, Stella Vosniadou has edited a fascinating collection of chapters on the current state of knowledge in the field of conceptual change research (Vosniadou, 2008b). *The Handbook* is a rich resource for anyone studying or enquiring into this area, but also deserves wider attention among all those working in education as researchers, teacher educators, or teachers.

The volume comprises 27 chapters arranged into six sections, and includes contributions from many of those considered leaders in the area. *The Handbook* does not offer a fully coherent account of the field: but that reflects the status of that field as one where much important work continues, and where some major debates are still underway. This is a ‘live’ field, and one that will remain active for some time yet. On the whole, teachers will not find many easy answers here to direct classroom work, for as the editor recognises, even where progress has been made, the outcomes of research are often still some way from being readily applicable in curricular and lesson design. Yet any reader interested in education will find much to consider, ponder, and reflect upon.

Informing Teaching and Learning

‘Conceptual change’ is the language of cognitive science, rather than of teaching: yet the term links to the very core of teachers’ work. One of the chapters suggests a definition of conceptual change as “the individual’s lifelong trajectory of understanding of a given topic or discipline” (Linn, 2008, p. 694), and that is something that is clearly of central interest to educators. As Brown and Hammer (2008) acknowledge in their contribution to *The Handbook*, even highly educated graduates can often readily be shown to demonstrate basic conceptual errors in topics that are prescribed in the school curriculum. Moreover, another contribution tells us how basic misconceptions can even be found among the experts in a particular field, such as qualified medical doctors (Kaufman, Keselman, & Patel, 2008). This reminds us that teaching does not always readily produce the conceptual change it is intended to!

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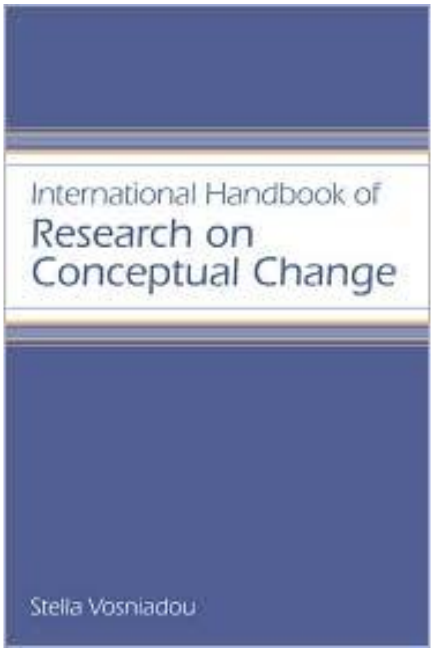
The key concepts in education are surely teaching and learning (Pring, 2000), and teachers and other educational professionals clearly operate with a strong notion of what these terms mean. Yet, people may commonly disagree on what counts as teaching and learning, and even when there is agreement, the terms label processes that can only be inferred indirectly. Teaching can be understood as *deliberate actions intended to bring about learning*. If one accepts such a meaning (with teaching understood in terms of intentions, not outcomes), then identifying teaching is potentially straightforward, at least as long as we can assume access to honest reports from those taking the role of teachers. If we prefer to see teaching as something that only happens when learning occurs – desired learning, moreover – then identifying teaching becomes somewhat more challenging.



This is because learning is not easy to define in straightforward and clear terms. If we are focussing on conceptual learning (rather than, say, skill acquisition) then learning could be considered as a change that brings about new personal knowledge – at least if knowledge is broadly defined, rather than limited to a philosophers' notion of 'reasoned true belief' (cf. Matthews, 2002). Such a definition is fine in principle, but rather difficult to operationalise for those researching into teaching and learning (Taber, 2009). For actually knowing when changes in a person's knowledge have occurred relies upon having unambiguous indicators of the person's knowledge at the present point in time (e.g. through interpretation of behaviours such as written and spoken responses to questions); and confident judgements that the same knowledge was not available prior to the 'learning'.

Yet proving the absence of something like knowledge can be quite tricky: most teachers are very familiar with students who appear to know something on some days, yet be completely oblivious of the same things on other days. Even when working with open and cooperative learners, the failure to elicit answers to certain questions on Monday, gives little assurance that they will remain ignorant on Tuesday. Similarly, evidence that they *do* know something on Wednesday cannot be assumed to imply they will demonstrate the same knowledge on Thursday. And Friday is yet another day. So the absence *of evidence of* knowledge cannot be assumed to be a sufficient reason to assume the absence of that knowledge.

We know that often the same learner has available a range of cognitive resources from which to construct their responses to our questions (for example, see the contribtion here by diSessa, 2008), and the precise construction produced will often be sensitive to contextual cues that may be subtle and not readily noticed by researchers. It is known that environmental cues can influence recall. When researching into conceptual learning the investigators can certainly have some control over such cues. However, much of the context for demonstrating knowledge is not so easily controlled: it is the internal, mental context. At any one time, the neural circuitry that is the physical substrate for mental representation of knowledge is in different states of activation – a range of different representations are at a level of activation (and so more readily accessed into consciousness) – and there is a dynamic flux in which representations are most active. Some, at least, of this activity is iterative. What the learner thinks about now, will be influenced in part by what they sense around them (such as a teacher or researcher's question), but also in part by what they were thinking about a few moments ago, that in turn was influenced by earlier thoughts (and so back through what their friend told them on the way to school, or what they heard on the radio whilst having breakfast, etc). The term 'stream' of consciousness sometimes seems very apt.

This presents a complex situation to investigate. We are unlikely to be able to test out all the possible response options available to a student both on practical and more fundamental grounds. Practically, we cannot expect our research informants to be motivated to offer responses to a spectrum of nuanced questions or test items so that we can somehow tease out just what they are resourced *to be able to* think about a topic or problem context (although the microgenetic approach discussed here by Siegler & Svetina, 2008 does begin to investigate learners in ways that approach this intensity). Moreover, if we believe that the nature of the individual's repertoire of conceptual resources will be influenced by the research context, then we must acknowledge that we will be trying to explore many facets of a situation constantly in flux: where any of those facets could be modified by any of the research probes at any point. And of course, if we did not accept that the individual's repertoire of conceptual resources could be modified by being presented with our research probes, then we would be taking a rather pessimistic view of the potential of teaching to bring about learning and conceptual change!

Similarly, except in the most trivial cases, few student behaviours (and usually by behaviours in this context we mean spoken or written comments and answers) can provide unambiguous evidence of knowledge. To take an example from physics education, there are many students who can give acceptable verbal formulations of Newton's laws of motion: but many of these will be found to fail to apply these laws when presented with some relatively straightforward examples (Gilbert & Zylbersztajn, 1985; McCloskey, 1983; McCloskey, Carmazza, & Green, 1980; Palmer, 1997; Savinainen & Scott, 2002; Watts, 1983; Watts & Zylbersztajn, 1981). We might argue that they have knowledge *of the statement*s of the laws, but not understanding of the laws themselves.

Yet we know that would also be overly simplistic. The research in this area suggests that it is quite likely that in any class of high school students tested upon this aspect of school learning, some individual learners would likely get the canonically correct responses in some examples, and be even be able to give adequate explanations; and also get the canonically correct responses in other examples, despite giving muddled or incorrect explanations for how their answers reflect the laws; yet get other examples wrong due to faulty arguments; and get further examples wrong, despite apparently using the principles in appropriate ways. Moreover, this cannot be explained simply in terms of differential difficulty of items, as different students will have different patterns of right and wrong answers.

In effect these behavioural responses may seem to offer more 'noise' than 'signal' if we are trying to characterise the essence of student thinking about this concept area, and, as is recognised in one chapter in *The Handbook* (Chi, 2008), evidence of conceptual change here would need to explore students' thinking across a suitable range of problem contexts. Moreover, given the point made above about internal mental context being outside the researcher or teacher's control, we might well find that if the same students were tested with the same items a week later, there would likely be shifts both from right to wrong, and wrong to right, responses and rationales. Often students have available manifold conceptions of the same topic, and the explanation or answer elicited at a particular moment is context-dependent (Taber, 2000). In effect, conceptual structures relating to such areas need to be seen as profiles rather than as binary dimensions, in the way described by Bachelard (1940/1968), and as developed in education by Mortimer (1995). This is one area highlighted in *The Handbook* as requiring further research attention (diSessa, 2008, p. 49).

Given all of these complications, it is perhaps not surprising to be informed in one chapter of *The Handbook* that,

> …the study of conceptual change encompasses a rich and diverse set of mental phenomena: sometimes dramatic conceptual change may underlie a sea of apparent conceptual calm while, at other times, a surface of marked conceptual change may derive from other sorts of changes in processing. (Keil & Newman, 2008, p. 99).

Personal or Social Construction of Knowledge

The inherent difficulties in investigating the nature of a learner's personal knowledge may be one reason why some commentators have in recent years shifted away from focusing on personal knowledge as the basis for considering learning, as being sure about what knowledge may be available within a learners' mind will always be problematic. A view of knowledge that sees it as situated within a social context, or distributed across a number of minds interacting in a collaborative venture (e.g. a lesson; a research interview) may become more attractive – the extra-mental 'social plane' is somewhat easier to access than an intra-mental plane. Whilst this is not to suggest this is the main motivation for those taking a constructionist view of knowledge, such a perspective does at least inherently acknowledge the role of social context in the demonstration of personal knowledge - even if it sometimes does so at the cost of excluding such a construct from the discourse of learning. Whilst socio-constructivist perspectives are considered in several contributions to Vosniadou's volume, it is not surprising that the limitations of such approaches often make them less attractive to researchers who focus on conceptual change: so that "the sociocultural perspective…needs to be modified to allow for the possibility to objectify knowledge" (Vosniadou, Vamvakoussi, & Skopeliti, 2008, p. 25). The editor and her coworkers argue that "the sociocultural perspective emphasizes the importance of cultural artifacts and the role they play as facilitators of thinking. But it does not explain how the human culture created these artifacts in the first place" (Vosniadou et al., 2008, p. 25).

More radical perspectives would completely eschew notions of personal knowledge (in a move reminiscent in some ways of the behaviourist turn in psychology). After all, if knowledge is only ever observed in action, in particular contexts – contexts that almost inevitably have a social dimension – then perhaps it makes more sense to consider knowledge production as arising from a system (minds interacting with each other and various artefacts, mediated through various symbolic tools), not an individual mind (Smardon, 2009).

Of course there is much sense in such a perspective: classroom learning for example is almost by definition learning that would not have happened without the classroom (the teacher, the other students, the cultural devices such as textbooks, audiovisual presentations). If we did not think this, then the logic of costly public education systems looks questionable! Yet there is still a large move from accepting the essential role of context in learning, to dismissing notions of individual learning and personal knowledge as either misconceived ideas (i.e. the notion of personal knowledge is no more than folk-psychology, a common way of making sense of experience that fits out intuitions, but actually is no more real than the tooth fairy) or at least irrelevant and unhelpful (it may be a meaningful concept, and may even refer to something real, but it has little heuristic value for a research programme if its referent can never be observed in a pure state).

Although socio-cultural approaches are referenced in *The Handbook*, inevitably the essence of a research programme in conceptual change tends to lead to most contributors seeing the individual learner as a meaningful unit of analysis, and ideas of personal learning and knowledge as very much real foci for study. In their contribution to *The Handbook*, Leach and Scott demonstrate how a socio-cultural perspective need not be seen as an alternative to exploring learning in the individual. So, for example, following Leont'ev, they describe how "individual learners must make sense of the talk that surrounds them, relating that talk to their existing ideas and ways of thinking. Learners must reorganize and reconstruct the talk and activities of the social plane" (Leach & Scott, 2008, p. 655). This type of approach would seem to offer a sensible way of acknowledging the social context of learning, without losing focus on the personal knowledge of the individual.

After all, any one of us who found ourselves isolated from the rest of society – for example stranded on the preverbal desert island – would continue to have knowledge that could be applied in lone actions in the asocial environment, and we would no doubt continue to undergo conceptual change. Of course it might be argued that this is because we have already internalised form the social plane and are still using resources made available to us before isolation. Indeed the isolate's mind would be populated with the internal mental models of former friends, mentors and loved ones, 'who' could continue to be engaged in a form of internal dialogue when a conversation is helpful to think things through. Survival then would surely depend upon the resources that had been built through social interactions earlier in life.

Although that might well be so, the same could be said about the umbilical cord that supported a person's early development in the womb: none of us would be here now without placental mediation between our developing bodies and our mother's blood supply. We experienced intimate physical communion as a prenate, and were provided with essential resources (food, waste disposal) to build ourselves: but that is not an argument for considering us as incomplete beings or biological epiphenomena once we are safely delivered and the cord is cut.

A Notion of Learning

Personal knowledge, it seems, is often nuanced and subtle, as well as sometimes being delicate and multifaceted. Learning might be best considered as a change in the behavioural *resources* available to a learner (Taber, 2009) – whether that is the resources needed to bend a football from the free kick; to play a scale on the viola; to differentiate a complex function; or simply to report that the capital of Italy is Rome. In each case, having the resources, means the behaviour *might* be elicited under favourable conditions; but as suggested above, not necessarily. From this perspective, conceptual learning would be a change in the conceptual resources available to learners – resources that can be applied to frame an answer, attack a problem, build an explanation, offer a synthesis etc. Whilst this seems a simple enough idea in principle, it begs the key question of what such resources actually are, how they might be organised in the mind and how they can change. These are not straightforward questions.

Part of the difficulty lies in the appropriate level of analysis for exploring conceptual change. It is generally accepted that conceptual learning is the result of changes at the neurological level – and that it may ultimately be due to changes in the synaptic connections between neurons in the brain (mainly the cortex). However this is not a useful level at which to explore conceptual change, both because we have no ready methods for observing synaptic changes during classroom learning, and because we have no way to map between individual neural connections and – for example – a person's understanding of fiscal policy, acidity, or the causes of the industrial revolution. Perhaps such mapping may one day be possible, but it seems likely that any such mappings would be both very complex and idiosyncratic, so at best such information would only offer general ideas to inform pedagogy.

For example, brain research offers a good basis for considering how over a period of time memories that originally rely upon temporary neural connections between different regions of the cortex and the limbic system (the medial temporal lobe) are consolidated through the establishment of strong direct linkages within the cortical network (Alvarez & Squire, 1994). This is useful in making sense of aspects of learning, remembering and forgetting at a general level, and has potential for both (a) understanding some learning difficulties and (b) giving theoretical support in general terms to the importance of reinforcement in teaching. Yet this is some way from offering specific advice on ideal patterns of reinforcement that might be adopted to support specific learning about quadratic equations rather than learning about climatic zones or the use of metaphor in romantic poetry.

Rather, conceptual change research is focussed less on the physical substrate (neural architecture) than on the components of knowledge representations (Taber, Forthcoming) – that is structure within the 'mind' (which of course is an abstract if useful notion), rather than in terms of location in the brain. So what many researchers in this area are seeking to do is to build models of how *representations of* conceptual knowledge are constructed, organised and modified within a hypothetical cognitive structure that is only loosely understood in terms of actual brain structures. Given this, it is hardly surprising that progress is difficult.

Representing Knowledge Structures

A key problem is the best way (or ways) to represent conceptual structures. When people try to represent knowledge publically they might use hierarchies, typologies, conceptual maps and so forth, but it is not clear how our personal conceptual knowledge is represented internally. Introspection is not that helpful here, as when we are asked to think about such things, we are processing what we have learnt by activating and processing representations in working memory (Baddeley, 2003): yet working memory is a very limited capacity facility, and we have little insight into the form the 'information' being processed was taking whilst in memory 'storage' prior to activation.

This gives scope for researchers to present models based on the clues available from studies into student learning and thinking. Unfortunately, however, these clues do not offer a clear, simple preferred model, and there are major active debates within the research community about the best forms for such models to take .

The coherence of the learner's knowledge

A key debate in the field concerns the level of coherence of the learner's knowledge. That is, whether people tend to have knowledge that is largely coherent and internally consistent, or more like isolated islands of knowledge that are not strongly linked, and so may often actually be inconsistent. A number of the contributions in *The Handbook* consider this issue, and whether it is appropriate to consider the learner's knowledge to be theory-like (for example, see the contribution by Brown & Hammer, 2008). There has been a vigorous discussion of this issue in science education, where the evidence seems very ambiguous as some researchers find students present coherent, consistent and stable ideas, and others elicit highly labile, contradictory and very context-dependent thinking. The conclusion to be drawn from this would seem to be that the question should not be 'whether' learners' knowledge is represented in coherent, theory-like ways, but 'under what conditions' does it take this form (Taber, 2009). Likely possible considerations would seem to include student age and ability, the nature of the concept area itself, familiarity with the topic, and quite possible the manner in which it has been met (e.g. taught).

In *The Handbook,* Vosniadou reiterates findings that suggest there are some areas of knowledge where people generally seem to intrinsically develop well integrated and organised thinking, implying knowledge representation that might be considered to be theory-like: "it appears that at least four well-defined domains of thought can be distinguished and considered roughly as 'framework theories' – physics, psychology, mathematics, and language" (Vosniadou et al., 2008, p. 16). These particular areas may be understood as reflecting domains (Hirschfeld & Gelman, 1994) where selection pressure may well have acted on human ancestors during evolution (Mithen, 1998), and so some genetic predisposition to developing particular patterns of thinking (which were associated with survival in the environment in which our ancestors lived) can be understood.

However, in another contribution to *The Handbook*, diSessa suggests that those describing the learner's thinking as coherent are being selective, and that even "expert understanding is not monolithic, homogenous, and logically consistent" (diSessa, 2008, p. 47). Human knowledge and thinking is inevitably found somewhere on a dimension that runs from totally ordered and coherent to completely disorganised and incoherent: where *both* poles surely represent 'ideal' theoretical cases. That is, we are all usually somewhere along the scale. Whereabouts depends on idiosyncratic factors, and will vary from domain to domain – so precocious young chess masters can demonstrate highly organised knowledge of the game, allowing them to annihilate much older players on the board, whilst retaining immature knowledge and understanding typical of their age in areas away from their special interest. The school subject teacher will demonstrate relative expertise in her curriculum area compared to her students, but may feel humbled when attending a lecture by a top researcher in her discipline. If she talks to the expert after his presentation, however, she might find that he offers a very vague and disjointed account of how his special topic relates to the broader subject in the school curriculum: a focus where the teacher has highly detailed and coherent knowledge.

The grain-size of cognitive elements

Strongly linked to the argument of coherence, is the issue of the appropriate grain size as a unit of analysis in studying conceptual structure (e.g., diSessa, 2008, p. 37). As we have seen, Vosniadou herself discusses 'framework theories', and uses these as the basis for explaining many identified learning difficulties. For her, the research evidence suggests "that concepts are embedded in domain specific 'framework theories' which represent different explanatory frameworks from currently accepted science and mathematics" (Vosniadou et al., 2008, p. 15). However, diSessa argues the need for more investigation at what he terms "sub-conceptual grain size" (p.55) and in particular the intuitive level, i.e. processing at the level of 'preconscious thinking' (Taber, Forthcoming). He suggests that: "we must necessarily say a lot about intuitive mental ecologies to account for their properties and to account for the emergence of new concepts" (diSessa, 2008, p. 55). For diSessa, resources at this intuitive level may be applied quite broadly across a range of domains, being effectively built into - or perhaps better understood as being cloned for (Karmiloff-Smith, 1996) – explanations that can be developed in different contexts.

These may seem esoteric arguments, but the models produced by researchers, are not only intended to explain existing findings, but also to be the basis of prediction: for example predicting how to best approach teaching particular topics. For example, Chi and her colleagues have interpreted the tenacious nature of some reported student conceptions at odds with canonical knowledge as being primarily ontological in nature leading to "categorical inferences and attributions [that] will be erroneous, creating a barrier to correct learning with deep understanding" (Chi, 2008, p. 65). So, for example, in physics, heat is seen as *a process* during which energy is transferred. However for many pupils, heat is seen as a fluid-like substance that 'flows' in a very literal sense (a notion, which of course recapitulates now discredited but once respectable scientific ideas about heat). For Chi, concepts are arranged in hierarchical ontological trees, and that the learner's basic ontology (their fundamental commitments to the kinds of things that actually exist in the world) is based around a small number of discrete trees. This would explain the tenacious nature of, for example, students' idea about heat, as their conception of heat is on the material/substance tree, whereas the physicist's notion is part of the process tree: and simply shifting concepts between completely different ontological trees is not possible.

This suggests that where pupils have a notion of heat as material, there is no point teachers trying to help them evolve their idea towards the scientific model: rather the teacher will need to start building up a totally new concept in parallel, which is understood as a process, and can in time (hopefully) take over as the way of understanding heat. So Chi's model, when applied generally, offers a way of predicting where teachers can expect learning to be evolutionary (and so should work at nudging existing thinking), and where they have to plan a conceptual revolution (Thagard, 1992), by helping the learner construct a new, alternative way of thinking that will hopefully one day be recognised to have sufficient explanatory power such that it usurps the old way of thinking. Discussing his own tree-like model in *The Handbook*, Thagard (2008) suggests there are nine graduations in types of conceptual change.

Although not everyone adopts Chi's model, it is widely recognised that from quite early in life humans do start to recognises that the world is populated in terms of different 'kinds' of things. So, in their chapter in *The Handbook*, Keil & Newman (2008, p. 93) argue that "there is now abundant evidence that even infants can have dramatically different expectations about agents who they consider psychological, as opposed objects that they view as merely mechanical". From an evolutionary perspective it makes sense for human children to soon recognise which of those objects around them might be capable of deliberate action, and which are innate and do not have their own purposes. Clearly this is one area where there is often over-assignment of agency, as Piaget's (1929/1973) work demonstrated well, perhaps suggesting that 'false positives' (such as considering the volcano to be an angry God) were generally less harmful to survival than failing to recognise some object in the environment as a potential rival for resources (especially perhaps when that object perceives us as lunch).

What Changes in Conceptual Change?

Without agreement on what the basic elements of cognition are, or how they may be structured such that knowledge is represented within the mind, the field of conceptual change research remains largely one with great *potential* to inform education, rather than a source of immediately applicable ideas. Ideas like framework theories, ontological trees, diSessa's phenomenological primitives and the like are all available to explain data, and potentially to inform curriculum development and pedagogy. Each of the approaches found in *The Handbook* has much evidence to support it, and selecting one perspective over another needs to be principled and not just made on an *ad hoc* basis of which idea seems to work in a particular context – that approach would give us the veneer of explanation, but no basis for deciding useful future action.

So what are readers to make of the different models and ways of thinking about conceptual change discussed in *The Handbook*? There certainly are findings that will be of interest to teachers. For example, I can see the value to a classroom practitioner of knowing that

> "just before discovery of a new approach, children shift from relatively consistent use of a single incorrect approach to a more variable incorrect behaviour…The rate of change tends to be gradual, with less sophisticated, earlier emerging approaches continuing to be used well after more sophisticated approaches are also

used" (Siegler & Svetina, 2008, p. 105)

Knowing about such patterns can certainly help a classroom teacher make sense of the complex patterns seen in pupil responses to learning activities. *The Handbook* is a rich resource, and there is much more here that can inform teaching, if sometimes only within specific contexts. So it is certainly useful for physics teachers to realise that research suggests that it is better to delay setting quantitative problems until students have a good qualitative grasp of the relevant concepts (Brown & Hammer, 2008), given that the physics teacher's instinct is often to move to numerical work as soon as possible because the concept can only 'really' be understood in mathematical terms. This is a dense resource (and in this review I have only touched upon some major themes and a small selection of examples), yet much of its content is still only suggestive for teachers.

However, for researchers (and advanced students), this *Handbook* offers an exceptionally useful overview of key ideas and research in the field. Moreover, the lack of a consensus approach to concepts, conceptual structures, and conceptual change shows just what potential there is for fruitful work in the field. It is surely not a matter of 'testing' the different theories here to find which are 'right': as all of the major ideas have robust evidence bases, even when they seen inconsistent with each other. The obvious conclusion is that conceptual change is complex, and research questions need to be less about 'which model' to use, than 'when' to apply different models. What we have is the equivalent of that elephant that was understood differently by the blind investigators separately probing its legs, trunk, ear, tusk etc. What will really take the field forward is a new synthesis that fits the different parts of the pattern into a more coherent framework that subsumes the various elements (Taber, 2008). This will involve *inter alia*,

- Understanding more about the nature and relationship of cognitive elements at different level of explicitness and implicitness (i.e. those directly available to the individual's consciousness; and those which influence thinking through preconscious processing and which only present outcomes to conscious awareness);
- Understanding more about the nature of the plurality of conceptions: whether understood as multiple frameworks, manifold conceptions, conceptual profiles etc;
- Understanding whether/when elements are somehow shared between different higher level assemblies, or whether/when they are cloned to provide components of higher level assemblies;
- Understanding how knowledge is represented in the mind in such ways that it can appear in different studies to exist as islands, coherent frameworks, hierarchies, etc;

- Understanding the properties of particular conceptions that are especially stable, or labile;
- Appreciating more the distinctions between what someone 'knows', what they *believe* to different extents, and what they can *imagine* as possibilities, and what shifts and interactions occur between these categories.

Arguments about *whether* knowledge construction draws upon primitive implicit elements; whether knowledge may be held within impermeable domains; whether personal knowledge can show the systematicity and coherence of formal theories, etc are surely now passé. Research has to now be interested in when, and under what circumstances these different characteristics are found (Taber, 2009); and someone who can bring about a synthesis that offers a coherent theory to organise the answers to these questions can significantly move on this field.

Messages for the Profession

So this is an extensive *Handbook*, offering a range of accounts of a complex field, to which I have offered just a few windows in this review. The book deserves careful reading, and is not done justice by the oversimplification of a review. It contains much useful exploration of ideas, even if this is likely to be of most use internally (within the field) to researchers, scholars and students.

However, if there is one message that *should* be taken away from this volume (and presented not just to teachers, but to administrators, and policy makers), it is the point made in the editor's introduction (Vosniadou, 2008a) that conceptual change is a slow process, where any observed apparent sudden changes are hard-won and simply offer the surface evidence of extended, preconscious processes influenced by many months of classroom experience. This is something that will resonate with many classroom teachers, who experience learning in their students as a gradual, incremental, often tentative evolution of thinking facilitated by carefully scaffolded, and drip-fed teaching inputs.

This may be what research tells us, but it is an uncomfortable message for many who work in the education systems of the world. Such a picture does not support inspection systems where teachers are expected to have discrete lesson objectives, which can be demonstrated to have been met during a single hour of observed teaching; nor assumptions that objective testing can readily assess whether such learning has occurred (see Brewer's 2008 contribution to *The Handbook*); nor notions that teachers can be unproblemtatically substituted by another qualified person who simply takes over a class at some point in the 'scheme of work'. It may be possible to plan education around notions of teaching and learning as a sequence of discrete teaching-learning episodes, for example to meet an accountability agenda, but we will not be teaching very much of real worth. In many subjects, we are not simply seeking learning of discrete simple facts or techniques, but rather meaningful conceptual change that leads to new ways of understanding aspects of the world. That requires a lot of mental work by the learner, with skilful support by the teacher. The *International Handbook of Research on Conceptual Change* shows just how nuanced conceptual change can be, and offers tantalising glimpses of how research in this area has considerable potential to inform pedagogy.

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Keith Taber was trained as a graduate teacher of chemistry and physics, and taught sciences in comprehensive secondary schools in England. He moved into further education where he taught physics and chemistry to A level, science studies to adult students, and research methods on an undergraduate education program. While working as a teacher, he earned his Master's degree for research into girls' under-representation in physics and his doctorate for research into conceptual development in chemistry. He joined the Faculty of Education in 1999. Dr. Taber was the RSC (Royal Society of Chemistry) Teacher Fellow for 2000-1, undertaking a project on Challenging Chemical Misconceptions. He was the CERG (Chemical Education Research Group) Lecturer for 2000.