Chapter 15
Modelling Conceptual Learning

> The 'learning paradox', as it has come to be called…poses a fundamental problem for constructivism: If learners construct their own knowledge, how is it possible for them to create a cognitive structure more complex than the one they already have?…The only creditable solutions are ones that posit some form of self-organization…At the level of the neural substrate, self-organization is pervasive and characterizes learning of all kinds… Explaining conceptual development, however, entails self-organization at the level of ideas – explaining how more complex ideas can emerge from interactions of simpler ideas and percepts. (Scardamalia & Bereiter, 2006, p. 103)

Theories of cognitive development discussed in the previous chapter focus on the way the apparatus of cognition develops (Leslie, 1984), rather than on how specific learning occurs. Although research on cognitive development has certainly been of interest to science educators (Bliss, 1995; Shayer & Adey, 1981), in recent decades there has been more interest in issues of specific learning and – in particular – conceptual change (Vosniadou, 2008b). In part this reflects an understandable division of labour, with developmental psychologists and other cognitive scientists primarily interested in development and mechanisms of learning and science teachers and science education researchers primarily interested in building up a body of knowledge that can inform science teaching. In that context, the work of Piaget and Perry (see the previous chapter) may seem to largely illuminate constraints on learning and so perhaps inform sensible choices of curriculum aims for different learner groups, rather than offer guidance on how to develop effective subject pedagogy in the science disciplines.

As I have discussed elsewhere (Taber, 2009b), from the late 1970s a research programme developed in science education commonly identified as 'constructivism' or the alternative conceptions movement (Gilbert & Swift, 1985), which focused on the contingent nature of learning, and in particular how new learning is shaped by current knowledge (Gilbert, Osborne, & Fensham, 1982). Piaget's theories were certainly constructivist, in the sense that he considered the operational stages of development to reflect structures of thought that were built upon and through earlier stages, and which provided the apparatus for developing new ways of thinking that could allow higher levels of thought to emerge (see the previous

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chapter). Such a model might seem to suggest that science teaching should be straightforward as long as the material to be taught was delayed until students reached the necessary level of operations. Given this, careful conceptual analysis could determine the sequencing of instruction that would facilitate attentive students to acquire canonical knowledge.

Yet it was well recognised, and has become increasingly well documented since, that carefully designed instruction given to apparently ready and suitably motivated learners often led to learning that was at odds with what was taught. Knowledge is not just information that can simply be transmitted as long as transmitter and receiver are functioning well and clear lines of communication have been established (see Chap. 9) – the student can see and hear the teacher and they speak the same native language.

Such a learning-as-information-transfer model is simplistic and does not reflect classroom experiences. Thus, earlier in this book (see Chap. 4), a model was set out of how we publically represent our knowledge in the public space using various symbolic systems (speech, writing, drawing, gesture, etc.) and others then have to not only sense those representations but interpret them (perceive them) in terms of their own sense-making resources. Thus, Ausubel's (1968, p. vi) dictum that 'the most important single factor influencing learning is what the learner already knows'.

Time and again research (e.g. as outlined in Taber, 2009b) has suggested that often:

- Learners' pre-instructional ideas can be stable despite being contradicted during instruction.
- Learners' acquired versions of taught concepts are distorted compared with what was intended, in senses that reflect aspects of their pre-existing thinking.

This is certainly NOT always the case (Gilbert et al., 1982), but it is very commonly so. From the perspective of Ausubel's theory of meaningful learning, this is not surprising:

> …the most important factor influencing learning is the quantity, clarity, and organisation of the learner's present knowledge…which consists of the facts, concepts, propositions, theories, and raw perceptual data that the learner has available to him [or her] at any point in time…The second important focus is the nature of the material to be learned. (Ausubel & Robinson, 1971, pp. 50–51)

Meaningful learning is a process whereby learners relate new information to existing conceptual structures, and so those pre-existing conceptual structures are inevitably critical for what will be learnt, as they determine the nature of new conceptual knowledge constructed.

Is There a Learning Paradox?

Earlier in this volume (Chap. 4), perception of objects and events in the world was considered, and it was suggested that after the stage of external stimuli triggering an initial sensory response, there is then a further process of 'processing' of the sensory signal before it is (sometimes) presented to consciousness: so that perceptions are usually considerable *interpretations* of raw sensory data. That is, we normally actually perceive objects and events rather than experience the 'blooming buzzing confusion' that William James (1890) suggested would comprise the newborn's experience of the world. This interpretation is an automatic part of the processing of information in the brain, before it reaches the stage at which the perception enters consciousness. A good deal of our experience is of this form.

However, this is not always the case. Sometimes we perceive objects or events in the world *without* recognising what they are. In these situations we may feel uneasy, or at least curious, and may actively seek more information – perhaps turn on the light, move closer, change our angle of view, clap our hands or wave our arms to see if there seems to be a response. Usually the perception resolves and we feel more at ease and sometimes foolish at not recognising something that now seems perfectly familiar. During such periods when we are unsure what we are sensing, we may consciously attempt to identify the object or event by a logical process of reviewing the information available (size, colour, etc.), although whether this plays a role in solving the 'problem' rather than simply helping us feel in control whilst the usual subconscious processes continue to search for an interpretation to present to consciousness is less clear.

On other occasions we experience phenomena that do seem to require us to actively (consciously) *make sense* of them. Here we are talking about something more than perception in the usual meaning. We may recognise the events and objects in our surroundings quite clearly – for example, who did what to whom and with what. However, we may seek a deeper form of understanding – perhaps to understand why something happened, what motivated certain behaviour, who was to blame for particular events, etc. This may require something more than perception in the sense of the interpretations that are presented to consciousness. In such situations we create a mental model to explain what we have perceived (see Chap. 11).

In the motto at the head of this chapter, Scardamalia and Bereiter (2006) raise the issue of the 'learning paradox', which – put simply – asks how we can teach ourselves things we do not already know. Under the traditional, folk pedagogy, notion of teaching as 'transmission' of knowledge, it was assumed there is a more advanced knower such as the teacher or the textbook author who can impart knowledge to the less advanced learner. Yet, if constructivists argue that each learner has to construct knowledge anew, then this creates the question of how it is possible to build up more advanced learning based only on existing less advanced knowledge.

There Is No Viable Alternative to Construction of Conceptual Knowledge

Hopefully, readers who have read this far into the book will appreciate two points about this alleged paradox. The first is that the paradox exists whether one is a constructivist or not, unless one accepts that conceptual knowledge exists in the world independently of minds in a form which allows us to acquire it. In this book it has been strongly argued that conceptual knowledge can only exist in minds.

The qualification ‘conceptual’ is important here. If we consider knowledge more generally as a kind of ‘know-how’ then there is plenty of knowledge around that does not rely on minds (Collins, 2010). Trees ‘know-how’ to grow taller than humans, and some species can commonly manage to outlive us without apparently ever forming any conceptions. Every cell has the ‘know-how’ to control a complex set of chemical processes; viruses have the ‘know-how’ to invade cells and make use of their resources; a zygote has the know-how to become a fully developed person (environmental conditions allowing). Yet the physical world itself has no conceptual knowledge of trees or metabolism or epigenesis in any helpful sense. A world without people would continue to have the ‘know-how’ for trees to grow and reproduce, but this is not conceptual knowledge. Conceptual knowledge is not out there waiting for humans to absorb it, but must be constructed through concept formation within a cognitive system.

If we accept that conceptual knowledge must be constructed then, the learning paradox exists regardless of whether we accept that once formed such knowledge can somehow be transferred or, better, reproduced, from person to person, or not. In this book, it has been argued that a person’s conceptual knowledge cannot be reproduced in a strict sense, only represented, allowing those representations to be used as information sources for others to construct their own knowledge. But regardless of this, somewhere along the line, someone formed a conception of ‘atom’, of ‘electromagnetic field’, of ‘chromosome’, etc. when such concepts had never existed before. This is not just the case for scientific concepts; of course, the same applies to the concepts of ‘inflation’, ‘prison’, ‘symphony’, ‘irony’, ‘ismism’, etc.

So if we reject the existence of some platonic world, where concepts have an independent existence *but are able to be accessed by people*, we must acknowledge that all concepts are constructed, that is, invented. The common misconception that Newton discovered gravity a few centuries ago (Pugh, 2004) is absurd, but although the detail is certainly wrong, some human being, or possibly protohuman, somewhere first reflected on regularities in their environment and conceptualised them in terms we might recognise as gravity. Since then, millions of others have constructed their own versions of a gravity concept: partly through their direct experience of the world and partly mediated through representations produced by teachers or through media such as textbooks of how others conceptualise gravity – often including representations of their teachers’ conceptualisations of how Newton conceptualised gravity.

Emergence Is a Widespread Phenomenon

The second point we might make about the learning paradox is that our experience of the world *is* that more complex structures do commonly emerge. Whether we consider the structure of galaxies, the earth, the ecosystem or individual living organisms, we find that the forces of nature bring about structures that did not previously exist. This is especially clear in the case of living things, where evolution has allowed the construction of incredible complexity. Incredible, literally, because it intuitively seems to most of us that the variety of living things, with their myriad special features, can only be the outcome of providence – that is guided by some higher intelligence capable of foresight in planning such complicated systems (Taber, 2013g).

Indeed, over 150 years after Darwin (1859/1968) published on the origin of species, some scholars continue to argue that the complexity of living organisms requires the involvement of an intelligent designer at least at some points in the process (Behe, 2007). Yet the theory of natural selection posits that, given enough time, such high degrees of complexity are possible through a combination of modest natural processes and an environment that in effect (i.e. without any sense of purpose or deliberation) selects those outcomes that better 'fit' in some way.

Emergence means that when a system is formed from several component parts that can interact, the system has new properties. Fully describing the system cannot be achieved by simply cataloguing the characteristics of the components as there are now interactions that were not present before, and so characterising the system requires including the relationships between components as the well as the components themselves.

There is of course nothing mystical about this. Arguably, if we want to fully characterise a single entity, which could become a system component, we should detail its behaviour in all potential contexts. A chemical analogy might be helpful here: to fully characterise an element (e.g. oxygen) we report its chemical *as well as* its physical properties. That is, we describe what happens to a sample of the element when it is warmed, cooled, pressured, subject to a potential difference, etc. and also what classes of substance it reacts with, under what conditions and which products are formed in each case.

If we react oxygen with hydrogen it demonstrates specific behaviour that is not due to the oxygen itself but rather is a restricted part of its potential behaviour when we select from all its possible potential behaviours by structuring the conditions under which we observe the oxygen. Any particular sample of oxygen cannot realise all of these potentials – once it has reacted with sodium it is not present in an elemental form to demonstrate its reaction with phosphorus. From *this* perspective, emergent behaviour is not something additional, but rather the narrowing of the vast potential field of interactions by the selection of a specific configuration.

This perspective can also be applied to conceptual development. We might consider, as an example, the concept of electromagnetism, which may be considered to be built from pre-existing concepts of electricity and magnetism. These previously distinct concepts came to be seen as related (as creative discovery, cf. Chap. 7), and, over time, as elements of an overarching concept of electromagnetism. This example is historical, but one that senior school and college students are often expected to recapitulate when studying physics.

The 'new' concept of electromagnetism is more than simply the concept of electricity 'plus' the concept of magnetism, as it also inherently involves the ways in which electricity is considered to be related to magnetism within a recognisable overall pattern. Yet these new relational features were always *potentially* present even if not actually formed before links were made. This is purely an argument about what can be conceptualised and is not referring to the nature of reality: the potential for phlogiston to be conceptualised existed both before it was accepted as a useful scientific notion and after it had been discredited. Learners demonstrate that all kinds of conceptualisations are potentially possible through the range of conceptions they develop about natural phenomena – whether it be orbital motion not requiring any force, atoms seeking to fill electron shells or trees that induce pregnancy if one takes advantage of their shade.

That is, inherent in the concept of electricity was the potential for it to be linked to the concept of magnetism in certain ways, and vice versa. So the formation of the new subsuming concept of electromagnetism brings 'new' features to light – and indeed facilitates a conceptual link with the concept of light! The recognition of these new features justifies the re-conceptualisation of electricity and magnetism under the subsuming concept of electromagnetism – there is no learning paradox here providing the cognitive apparatus supports the ability to (a) form concepts, (b) seek relationships between concepts and so (c) reconceptualise these existing concepts in terms of new identified/mooted propositional links.

Of course this example is meant purely for illustration. The logic of earlier chapters in the book suggests the example cannot refer to 'the' concepts of electricity, magnetism and electromagnetism, but rather particular instances of knowledge representations within particular minds, that is, the concept*ions* of individuals. That is, there are a great many potential ways one could find to relate the concepts of electricity and magnetism, not all of which would match the canonical science perspective which itself is informed and constrained by the interpretation of empirical evidence. Particular learners will have reasons for conjecturing certain relations to be possible and of potential importance – often informed by teaching, reading and their own experience of relevant practical work – but as we have seen that does not necessarily mean their knowledge is a 'true' account of the world.

Two provisos should be highlighted here. It is not implied that the pre-existing concepts of electricity and magnetism are unchanged by this process. They are certainly changed in acquiring new links, but also the formulation of the overarching concept, the new system of concepts, may lead to inconsistencies or absurdities that can motivate changes in the 'original' conceptions, that is, the features the distinct subsumed conceptions were assigned before the re-conceptualisation. This point is picked up below.

The second point to be addressed is a possible objection that my statement 'new relational features were always potentially present even if not actually formed before links were made' could be seen as acknowledging that the concept of electromagnetism does indeed already exist in some Platonic sense prior to its discovery by our hypothetical learner here or indeed any 'knower'. As so often, that depends how we define and understand our terms.

Given the existence of (e.g. human) minds able to develop conceptions, we can imagine a kind of conceptual phase space of the different conceptualisations that could exist. Within that conceptual space must, by definition, occur the concept of electromagnetism as developed by my hypothetical learner, and indeed that space must include ALL the conceptualisations of electromagnetism (as well of course anything else) that have ever formed in minds or ever will. Moreover, a vast, if not infinite, set of other conceptualisations that could be produced by relating electricity and magnetism also potentially exist in this space even if they will never be conceived in any mind. If that is what we mean by concepts having independent existence, then it is a trivial sense – and indeed relies for its existence on someone having a mind to conceptualise the conceptual phase space itself. This is rather different from the notion of ideas having independent ('World 3', see Chap. 4) existence outside of ('World 2') minds.

The Task of Modelling Learning

This rather philosophical exploration of the learning paradox leads to my discounting it as a serious problem for constructivist models of learning in science (or any other disciplines) providing that:

1. Learners have suitable apparatus to facilitate the concept construction process.
2. Learners have suitable apparatus to evaluate and select between potential conceptual constructions.

In modelling conceptual learning, then, we need to consider the mechanisms by which concept construction, modification and evaluation can take place. The cognitive system modelled earlier in the book (especially Part II) inherently offers that apparatus, so that we can agree with George Kelly (1963, p. 75) who argued that 'learning is not a special class of psychological processes. It is not something that happens to a person on occasions; it is what makes him [or her] a person in the first place'.

Concepts and Conceptions (Revisited)

Chapter 11 offered an analysis of the main types of knowledge component that might be considered present in a learner's cognitive structure. In that chapter it was suggested that the approach to understanding the terms concept and conception recommended by Gilbert and Watts (1983) would be followed there. The term 'concept' was reserved for 'formal meanings as part of public knowledge systems', whereas 'conception' was used to refer to the personal understandings of individuals.

Ezcurdia (1998) suggests that people may be said to have acquired the same concept (e.g. metal, an example used below) but would each have their own particular conceptions (e.g. of metal). So from this usage we could refer to someone acquiring a *concept* of metal – but their *conception* may not match the concept of metal held by others or some notion of the canonical concept. The terms concept and conception are therefore doing useful work in making the distinction between what is common and what is distinct: different people have the ‘same’ concept but their conceptions are different.

Similarly we could say that a person’s *concept* (e.g. of metal) may change over time because at different times they have different *conceptions*. Again we can use the term concept to refer to what is considered to have continuity and conception to refer to the particular – here at a moment in time. It is the ‘same’ concept in the sense in which the reader is the same person they were as toddler or the way a mature tree in the garden is the same plant as the sapling planted there many years before. This sameness is a matter of identity rather than being identical: in the way a ship is the same ship after a major refit or the way a political party or university department is considered the same party or department even after all the personnel have changed over time.

So the following parts follow the common usage of referring to individuals forming concepts (rather than conceptions) and undergoing conceptual (not conceptional) change. However, in keeping with Chap. 11 the term conception will be used when either specifying the particulars of a concept that distinguishes it from another person’s conception of the ‘same’ concept or the sequences of different conceptions involved when an individual undergoes conceptual change (e.g. see Figs. 15.4, 15.5, 15.6, 15.7 and 15.8).

Concept Formation: Developing Spontaneous Concepts

Concept formation seems to be a key attribute of the human cognitive system. We have innate tendencies to recognise certain regularities in our environment (see Chap. 4). The recognition of these patterns supports categorisations that have been in effect been tested for utility over human evolution. So, for example, we recognise ‘natural kinds’ of living things and moreover do so spontaneously. Someone has to tell us that a particular type of living thing is called a ‘cat’ or a ‘horse’ in our local language community, but we are born with mechanisms for identifying such types.

Many other concepts may be formed spontaneously without needing to be innate. The ability to recognise repeated patterns and so develop what are in effect expectations that allow us to categorise experience is an intrinsic feature of the operation of the cognitive system (see Chap. 4). Spontaneous concepts are not based on reflection upon experience, but the automatic working of the cognitive system in interpreting information from the environment. That is, such concepts are formed spontaneously because of the nature of our perceptual systems and the inherent pattern recognition mechanisms built into human cognition.

It is important to be clear that this neither means that we all spontaneously develop precisely the same conception of horse, nor that the conceptions we do develop are necessarily ‘correct’ in some technical sense such that any particular conception will match a canonical scientific concept. But we do readily develop working concepts in this way. As we have substantial common genetic inheritance as humans, and as we often experience similar environments, we would expect there to be strong similarities in many of the spontaneous concepts we develop.

This is the basis of implicit knowledge, such as that represented in p-prims (as discussed in Chap. 11), which is often used to guide our behaviour without conscious control of attention. The advantages of speed and automation that implicit knowledge provides allow us to act on such knowledge without pausing to reflect upon its nature or origins.

Introspection on Spontaneous Concepts

The implicit nature of this knowledge does not imply that we must completely lack self-knowledge in this regard. As was discussed in the last chapter, a key feature of human development is the acquisition of the ability to reflect upon our own thinking: metacognition (see Chap. 7) – perhaps due to something like Demetriou's hypercognitive system (Demetriou & Mouyi, 2011, see Chap. 14) model. Although some aspects of the processing in human cognitive systems occur away from conscious awareness and control, we can still reflect upon *the outcomes* of such thinking (e.g. I know I'm seeing it as a face, but actually it's just a coincidental pattern in the clouds, cf. Fig. 4.6).

There has been a debate about the nature of our concepts (Gilbert & Watts, 1983), for example, whether they are based on membership criteria (if it is a large animal, with four legs, a mane, a particular head shape, etc.) or prototypes (if it looks like this mental image I have of a typical horse), etc. Such an argument may be unhelpful if the apparatus for forming spontaneous concepts is based on neural networks which become tuned to perceived regularities in the environment, as these types of cognitive components would inherently seek a match through an inbuilt feedback mechanism and not in any directly verbalisable manner (see Chap. 5). So we can *reflect upon* how we know when we have seen a horse and might refer to the number of legs, the tail, the mane, the size of the beast, etc., but we do not actually know how we make the judgement using preconscious processing – we can only offer conjectures for how we know.

Forming 'Reflective' Concepts

Scardamalia and Bereiter (2006, p. 104) discuss how 'a dynamic systems explanation of conceptual growth posits (along with other kinds of interactions) ideas interacting with ideas to generate new ideas'. So, as an example, I may, through a creative process (Chap. 7), coin a new concept I label as 'supermarines'. My conception of supermarines is vessels that may be used for transport on the surface of the sea, and

I will include as examples boats, ships, rafts, dinghy, catamarans, canoes, yachts, seaplanes (flying boats), etc.

Karmiloff-Smith (1994, 1996) has argued that a key feature of the cognitive system is an ability she calls ‘representational redescription’, which allows the cognitive system to form new types of representations of the information already represented: ‘to exploit internally the information that it has already stored, by redescribing its representations or, more precisely, by iteratively rerepresenting in different representational formats what its internal representations represent’ (1994, p. 699). In general, Karmiloff-Smith argues, this process allows knowledge to be represented at increasingly explicit levels. So, an implicit knowledge element such a p-prim might become re-represented at a level at which *the new representation* can be consciously accessed and reflected upon, perhaps in an iconic form, or perhaps as a verbalisable concept.

That is, in terms of our typology of knowledge elements discussed in Chap. 11, elements of conceptual knowledge which fall under the ‘implicit’ branch of Fig. 11.1 are not, and cannot themselves be, promoted to an explicit status but can *become represented* elsewhere within the system by a new representation formed within a category on the ‘explicit’ branch – which allows us to consciously access and operate with (not the original implicit knowledge element itself but) the explicit representation of the implicit knowledge element.

Acquiring Academic Concepts

A key distinction made by Ausubel (1968, 2000) was between ‘rote’ learning, which is learning material so it could be recalled verbatim without understanding, and ‘meaningful’ learning where the material to be learnt was subsumed within existing conceptual structure (see Chap. 5). Although it will be suggested that this should be considered a matter of degree rather than a dichotomous classification, it is a commonly used distinction and one of practical importance in teaching and learning.

Learning by Rote?

Learning that is *purely* ‘by rote’ may seem to offer the strongest example of the learning paradox, as it seems to suggest learning of material for which there is no relevant existing structure within the cognitive system to provide interpretation or linkage. However, when discussing rote learning, we are normally considering learning of verbal material, and so learning which is supported by the language ‘modules’ that we know are part of the normally developing cognitive apparatus of all humans (see Chap. 6). So if we learn some lines of poetry without understanding their meaning, they are still likely to include some familiar words and to follow a familiar grammatical form. Even ‘nonsense’ poetry follows grammatical rules and uses the phonemes of the local language.

Rote learning used to be very common in formal instruction and indeed still is in some national traditions (Boyle, 2006; Eickelman, 1978). In extreme form, this might mean reciting phrases such as 'the square of the hypotenuse in a right-angled triangle is equal to the sum of the squares of the other two side' or 'the rate of change of momentum of a body is directly proportional to the applied force and occurs in the direction of the applied force' as if being able to produce the statements accurately at will is itself a worthwhile learning goal. Learning by rote is nowadays generally considered poor educational practice, and in science teaching we seek meaningful learning as far as possible: that is, learning that makes sense to the learner though being related to an existing conceptual structure (Ausubel, 2000).

Rote learning clearly works in one sense, in that people *can* learn material by rote and for some material this may be useful or even necessary. An example might be when acting in a play – although, even there, performance based simply on memorising a text is unlikely to be of high quality. Generally, rote learning by itself is not very useful if it does not lead to understanding, but rote learning may sometimes be *part of* the process leading to understanding (Tavakol & Dennick, 2010) or may at least allow the learner to enter into discourse with others about what they have learnt.

The potential for rote learning seems consistent with the types of mechanisms responsible for implicit knowledge elements, in the sense that repetition provides repeated experience of the same pattern which at the physical level, see Table 3.4, can presumably lead to sequenced firing of the same neural components, leading in turn to strengthening synaptic connections; that is, the tuning of neural circuits that will more readily be activated.

Conceptual Growth: Subsuming Learning Under Existing Conceptual Structures

We can learn that Paris is the capital city of France, that sodium has atomic number eleven, that Equus refers to horse and a great deal of other apparently arbitrary information. This information is arbitrary when *to the learner* there is no obvious rationale for why Paris is called Paris rather than something else. Such items would need to be learnt by rote when they cannot be understood in terms of existing conceptual structure, although this is always a matter of degree.

Someone who did not speak English and learnt to recite that 'Paris is the capital city of France' without knowing what the terms France, Paris or capital city referred to would have learnt by rote to a much greater extent than an English speaker who knows of France and already had a concept of capital city. The challenge of the rote learning for this latter person is largely remembering the name of Paris, whereas for the non-English speaker the task is to learn an incomprehensible string of sounds. That is, for the person who has acquired the concept of capital cities, the new knowledge element, the meaning associated with the name Paris, fits within an existing schema (see Chap. 11) in which capital cities have a particular relationship with countries and where a number of existing examples are likely known, for example:

Country	Capital
England	London
USA	Washington, DC
France	[slot for the name of the capital city of France]

A lot of learning involves these kinds of processes – learning new examples or properties that can be added to our existing 'conceptual map' of the world. Mnemonics used as memory aids work in a similar way, by making links with material already present in conceptual structure. So, a learner who knows that gold and iron and copper are metals might add additional examples such as sodium and uranium (this example is developed further below). Indeed, this type of learning can be represented by showing additional propositions added to a concept map (see Chap. 12).

Learning 'Academic' Concepts

Vygotsky (1934/1994) referred to 'scientific' or 'academic' concepts, which are only acquired through formal instruction – and so are 'the purest type of nonspontaneous concepts' (p. 365) – as opposed to what Piaget had called 'spontaneous' concepts that the individual can acquire through their direct action in the physical world. Those spontaneous concepts (i.e. conceptions) derive from everyday experience, and although they do not necessarily remain tacit, this origin is significant:

> The child becomes conscious of his spontaneous concepts relatively late; the ability to define them in words, to operate with them at will, appears long after he has acquired the concepts. He has the concept (i.e., knows the object to which the concept refers), but is not conscious of his own act of thought. The development of a scientific concept, on the other hand, usually begins with its verbal definition and its use in nonspontaneous operations – with working on the concept itself. It starts life in the child's mind at the level that his spontaneous concepts reach only later. (Vygotsky, 1934/1986, p. 192)

Figure 15.1 represents the difference between spontaneous and academic conceptions using the form of representation adopted earlier in the book. In the figure, the student is shown directly perceiving an object, a plant, and being taught about the concept of 'primary producers'.

Academic Concept Formation

Spontaneous concepts are likely to derive from the cognitive system's inherent pattern recognition ability, when experiences that seem similar lead to the formation of a knowledge element for that pattern of experience. For example, certain types of

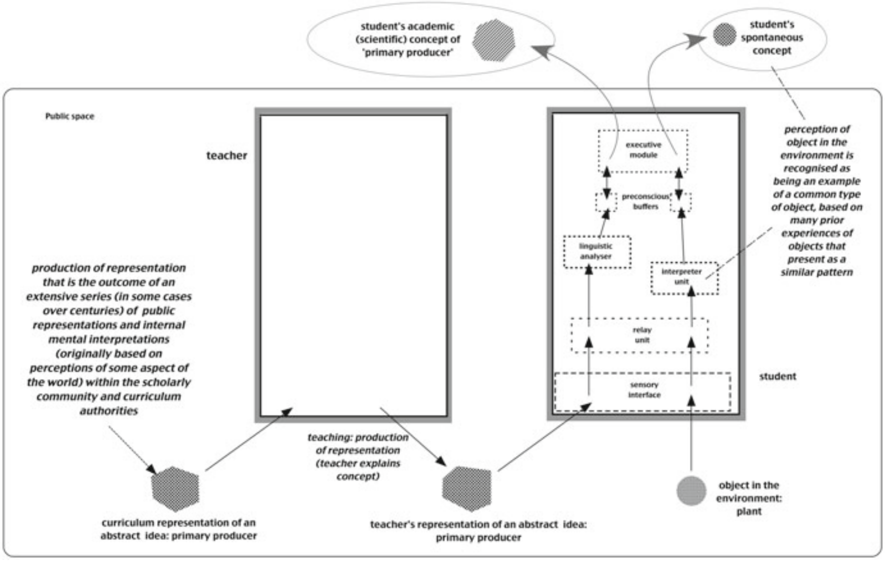

Fig. 15.1 The origins of academic and spontaneous concepts

objects in the environment, which are green, anchored in the soil, have laminal structures, etc. come to be seen as a class of things.

Academic concepts are usually presented through language, which is analysed in specific areas of the brain where specialised interpretative apparatus has evolved to handle this type of input (see Chap. 6). This might seem to 'short-circuit' the learning process by allowing the individual to develop concepts without extensive personal experience of the referents (Karmiloff-Smith, 1996). However, as suggested above, such concept learning is only meaningful when it can be interpreted as making sense in terms of existing conceptual structures – which ultimately means it depends upon direct experience of the world (Lakoff & Johnson, 1980b). Thus, verbal learning can occur providing both the apparatus and some relatable conceptual substrate are available to the learner. From this perspective what is learnt has the meaning imposed by being related to an existing conceptual structure and will not necessarily acquire the meaning intended by a teacher. This is a premise of the constructivist perspective on learning (Taber, 2009b).

Concept Modification

Earlier in the book (see Chap. 11) the knowledge components that were tacit were compared with those, such as a learner's conceptions, which they can directly access and reflect on. Once conceptual knowledge has been formed, there is the potential for it to be modified within the conceptual system. Caravita and Halldén offer a view of learning, where:

> [learning is not seen] as an event of mere replacement of old ideas by new ones, but as a process which occurs in a system where conceptions of specific phenomena are only one of the components. Organization, refinement and differentiation among contexts are other important and observable aspects which continuously enlarge the power of the system to perceive and interpret reality. (Caravita & Halldén, 1994, p. 90)

Whereas tacit knowledge components such as p-prims are encapsulated, so that once established in the system, they remain stable and unchanged, conceptual knowledge has the potential to be related, compared and interlinked in various ways. Various types of modifications are possible.

Piaget (1970/1972) saw a process whereby experience provided new material to be incorporated into conceptual structure (assimilation), sometimes leading to inconsistencies in the system (disequilibrium), which could be fixed by modifying existing knowledge (accommodation) to bring the system back to coherence (equilibrium).

Disequilibrium only occurs when we notice something that does not fit with existing ideas, whereas the nature of the perceptual system is such that most commonly we manage to *interpret* new information in ways that are consistent with our existing conceptual structure (see Chap. 4). Therefore, only when a new learning experience cannot be made sense of in terms of current knowledge are we likely to experience the 'cognitive dissonance' (Chapanis & Chapanis, 1964; Cooper, 2007) produced by something that confounds our expectations and therefore cannot be perceived in terms of existing knowledge.

We might envisage one type of conceptual development as simple growth in the range of application of a conception as more examples that can be subsumed are discovered. So a student who has a conception of metal that includes knowing that iron and copper are metals may go on to learn that manganese and zinc are additional examples of metals, without substantially changing their existing conception of what a metal is.

We can also envisage conceptual development that brings about more fundamental changes in the nature of the learner's conception – such as when the everyday notion of what it is to be a metal is related to new learning about the canonical chemical concept of metal. Sometimes there may be potential for 'changing one's mind' such that existing conceptions are found to be inadequate, requiring changes in aspects of existing understanding. A conception of metals, for example, incorporating lifeworld ideas that metals are magnetic, metals are hard and metals are solids may be challenged by new learning (this example is developed below).

It would seem that characteristics of progression in learning might be understood as:

- Increasing integration of conceptual knowledge by identifying links between conceptions
- Increasing coherence of knowledge by identifying apparent inconsistencies and seeking to interpret them

Interpretation may involve resolving the apparent inconsistency (as, e.g. recognising it as due to alternative models of the same target) or recognising an apparent flaw in personal knowledge that requires attention.

It is known that the human cognitive system has inbuilt mechanisms for seeking greater integration of knowledge that do not rely on conscious interrogation of a person's knowledge base (see the discussion of memory consolidation in Chap. 5); however, metacognition – conscious interrogation of and reflection on one's own knowledge (see Chap. 7) – also plays an important role in identifying apparent inconsistencies between different (explicit) knowledge components.

Vygotsky's Notion of Concept Development

Vygotsky's model of conceptual development involved interaction, and a kind of convergence or hybridisation, between spontaneous and academic concepts. Vygotsky suggested that in effect spontaneous concepts allow academic concepts to be meaningful and academic concepts provided the framework for making spontaneous concepts explicit. Vygotsky (1934/1986, p. 148) described this process using a spatial metaphor involving 'two different paths in the development of two different forms of reasoning'. Vygotsky talks of academic or scientific concepts being formed higher in the system than spontaneous concepts, as 'a scientific concept… starts its life in the child's mind at the level that his spontaneous concepts reach only later' (p. 192). This is possible because such concepts are 'mediated' (p. 194).

The two types of concepts interact and converge: the academic concepts moving 'downward to a more elementary and concrete level' (p. 193) and the spontaneous concepts moving upwards. That is, they 'develop in reverse directions: starting far apart, they move to meet each other' (p. 192):

> In the case of scientific thinking, the primary role is played by initial verbal definition, which being applied systematically, gradually comes down to concrete phenomena. The development of spontaneous concepts knows no systematicity and goes from the phenomena upwards towards generalizations. (Vygotsky, 1934/1986, p. 148)

This spatial metaphor, of vertical movement towards convergence, is represented in Fig. 15.2. This metaphor, focusing on shifts along a concrete-abstract dimension, however, oversimplifies the process Vygotsky describes. For Vygotsky, the shifts that occur in these initially quite distinct types of conception are facilitated though being related to concepts from the other category, through a kind of mutual development:

> In working its slow way upward, an everyday concept clears a path for the scientific concept and its downward development. It creates a series of structures necessary for the evolution of a concept's more primitive, elementary aspects, which give it body and vitality. Scientific concepts, in turn, supply structures for the upward development of the child's spontaneous concepts toward consciousness and deliberate use. Scientific concepts grew downward through spontaneous concepts; spontaneous concerts grow upward through scientific concepts. (Vygotsky, 1934/1986, p. 194)

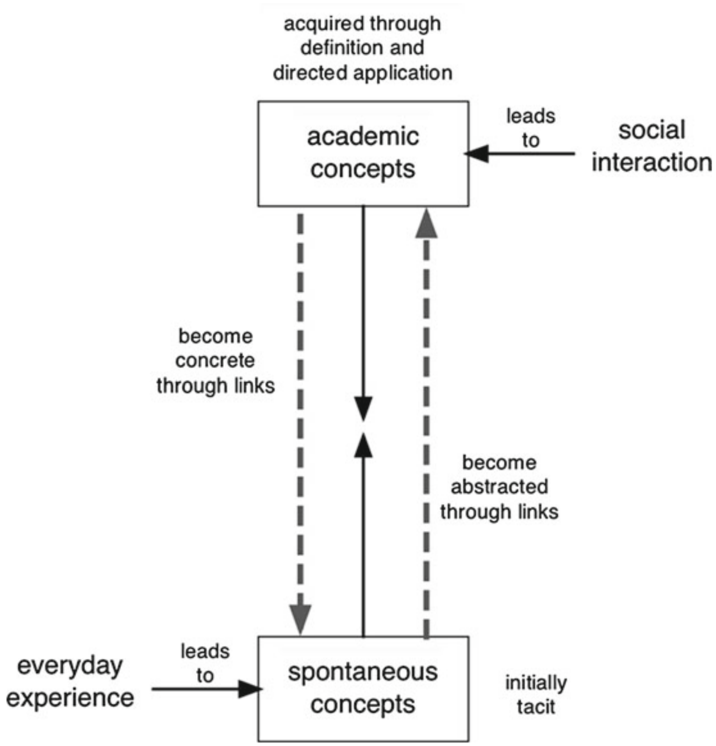

Fig. 15.2 A representation of Vygotsky's spatial metaphor for conceptual development

Vygotsky was writing the best part of a century ago, and parts of his description may now seem outdated. He notes that spontaneous concepts appear before the learner is aware of them or is able to define them or to consciously apply them at will (p. 148). That is, this type of knowledge is initially implicit. Vygotsky suggests that scientific concepts facilitate the shift to explicit knowledge. This, however, need not be the case: the presence of something like the hypercognitive system (see Chap. 14 and the discussion of metacognition in Chap. 7) allows us to *become aware* of at least some of our initially implicit knowledge (e.g. personal constructs; see Chap. 11) and so make them explicit. This need not require the mediation of academic (taught) concepts but can occur through the process of representational redescription discussed above.

Even if the formation of what might be termed 'reflective' concepts, that is, concepts open to conscious reflection, from initially tacit spontaneous concepts may not require the mediation of taught academic concepts as Vygotsky suggests, once the reflective concepts have themselves been formed, there is a question of their relationship with academic concepts acquired through language and social processes (e.g. teaching).

As noted earlier (see Chap. 12), some commentators have suggested that concepts derived from everyday experience largely form a discrete system represented separately in conceptual structure from taught concepts (Claxton, 1993; Solomon, 1992). From this perspective, the task of relating these two systems is seen as challenging for the learner. Vygotsky's research, however, led him to conclude that 'the development of spontaneous and academic concepts turns out as processes which are tightly bound up with one another and which constantly influence one another' (1934/1994, p. 365).

Rather than forming somewhat isolated categories of thought, Vygotsky argued that the two 'types of concept are not encapsulated in the child's consciousness, are not separated from one another by an impermeable barrier' but rather that 'the dividing line between these two types of concepts turns out to be highly fluid, passing from one side to the other side an infinite number of times in the actual course of development' (p. 365). According to Vygotsky, our spontaneous and academic concepts 'do not flow along two isolated channels, but are in the process of continual, unceasing interaction' (p. 356).

This does not seem consistent with Solomon's (1983, 1992) notion of lifeworld knowledge being a separate domain to school learning of concepts. However, if Solomon's notion of there being distinct domains of knowledge is understood in terms of the topography of learners' cognitive structures – there being separate systems for representing lifeworld and school science concepts in different locations – then it runs into difficulties as her distinction does not seem to fit well with the actual distinctions between different types of knowledge elements elicited from learners (as discussed in some detail in Taber, 2009b, pp. 241–251). Solomon's ideas may be better understood in terms of students having to learn to participate in different discourse practices in science classes (Gunckel, Mohan, Covitt, & Anderson, 2012), rather than being about the representation of conceptual knowledge itself. This point is developed later in the chapter.

Vygotsky's model then refers to a high level of interaction between spontaneous and academic concepts and the development of each of these types of concepts towards a more hybrid state: spontaneous concepts deriving from concrete experience acquiring abstract nature and academic concepts acquiring concrete referents.

Melded Concepts

Vygotsky's description of this process maintains the labels of spontaneous and academic for the different types of concept that are interacting. Yet the implication of his account is that this distinction cannot be fully retained. Rather, by relating the academic concepts mediated through social processes to the spontaneous concepts developed through direct experience of the natural world, new conceptual structures form that subsume both. Through such a process people develop concepts that are hybrid forms: melded concepts.

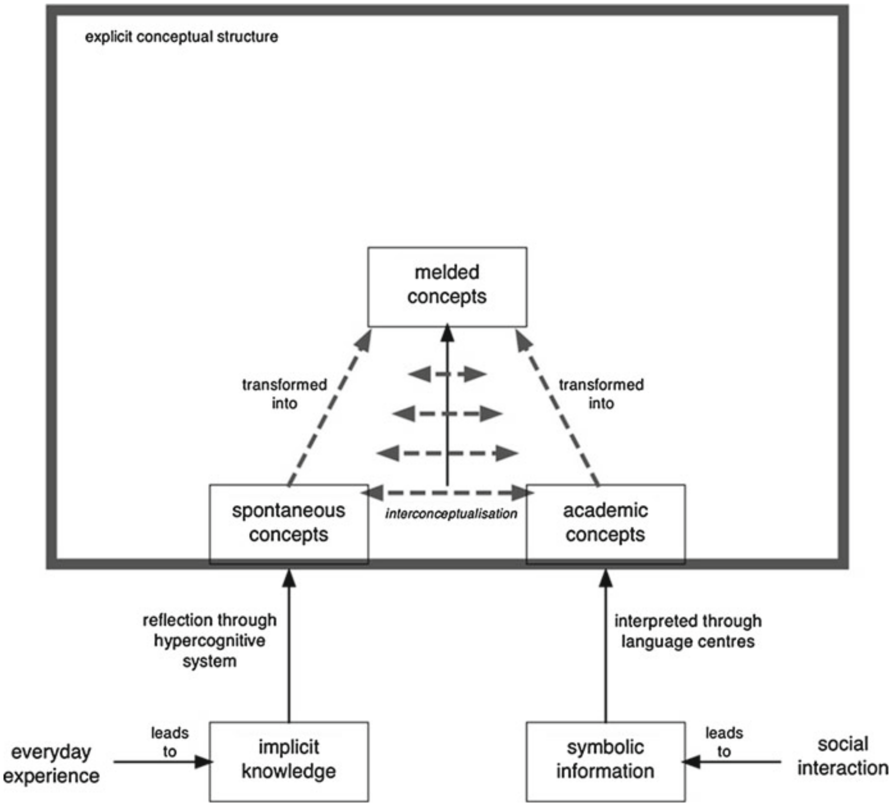

Fig. 15.3 A modification of Vygotsky's scheme: the development of melded concepts

This suggests that the distinction between spontaneous and academic concepts relates primarily to *the origins* of concepts, but due to the dynamic nature of memory this distinction may afterwards be broken down by the interactions Vygotsky describes. In some cases there might be considerable integration of what begins as a purely spontaneous concept with what has been learnt through verbal instruction. Through what might be termed 'interconceptualisation', what were originally discrete spontaneous and academic concepts evolve into a melded concept that draws upon both an experiential base in direct experience of the natural world *and* culturally mediated learning relying on communication through a form of language. Certainly it would seem this is often the ideal we look for in teaching science.

We might therefore reconceptualise Vygotsky's description as something more like Fig. 15.3, where both spontaneous concepts and academic learning are processed initially through perceptual apparatus, before becoming represented as explicit knowledge in conceptual structure, allowing the potential for linking, and possibly some level of integration.

Here, in Fig. 15.3, an alternative spatial metaphor is employed, where rather than spontaneous and academic concepts moving up and down (respectfully) to meet each other, both are originally represented near the periphery of conceptual structure, but through being linked and used to interpret each other, come to occupy a more central position. This representation borrows from the metaphor of surface and deep learning (Chin & Brown, 2000). That is, conceptual structure is here conceptualised spatially not in relation to physical location within the cortex, but in terms of connectedness, with more connected material seen as more central.

This process highlights the value of language and social mediation in human learning. Without such mediation, the individual learner would only form concepts based on interpretation of direct experience. Reflective concepts could certainly form, and be modified by new experience in the sense Piaget describes. Moreover, the inbuilt tendencies of the cognitive system to relate the contents of conceptual structure, notice inconsistency (disequilibrium) and modify the system of concepts towards greater coherence would act on spontaneous concepts – but would always be limited to the data provided by perceptions of personal experience of the world.

Vygotsky points out how cultural mediation through language allows us to also develop what are initially spontaneous concepts not only through reflection upon our own experiences but also through our interpretations of the public representations of the reflections of others. Sometimes, of course, this process involves many stages of iteration such that we can consider there to be, at least in principle, canonical versions of concepts (see the discussion of public knowledge in Chap. 10).

As Vygotsky recognised, academic concepts can only be meaningful through being related to existing concepts that ultimately are grounded in spontaneous concepts formed through personal experience and this inevitably means that academic concepts may be acquired in idiosyncratic ways. Moreover, the possibility of forming melded concepts opens up the conceptual system of any learner to a potentially vast sources of 'secondary data' based upon the public representations of the knowledge of other members of the community. In a global society with books, radio, television, the Internet, etc., this in effect means that every learner can be part of a network of billions of people able to represent their personal knowledge in the public space where it can be perceived and interpreted by others.

A Hypothetical Example of Concept Development

It certainly seems that conceptual development involves a number of distinct types of changes to conceptual structure. This can be illustrated by using the example of a student's learning about the 'metal' concept. The example here is hypothetical, designed to highlight some of the different aspects of concept development, but reflects the kinds of changes reported in studies.

Figure 15.4 represents a hypothetical student's concept of metals before formal instruction in the topic in middle or secondary school science. Most students will

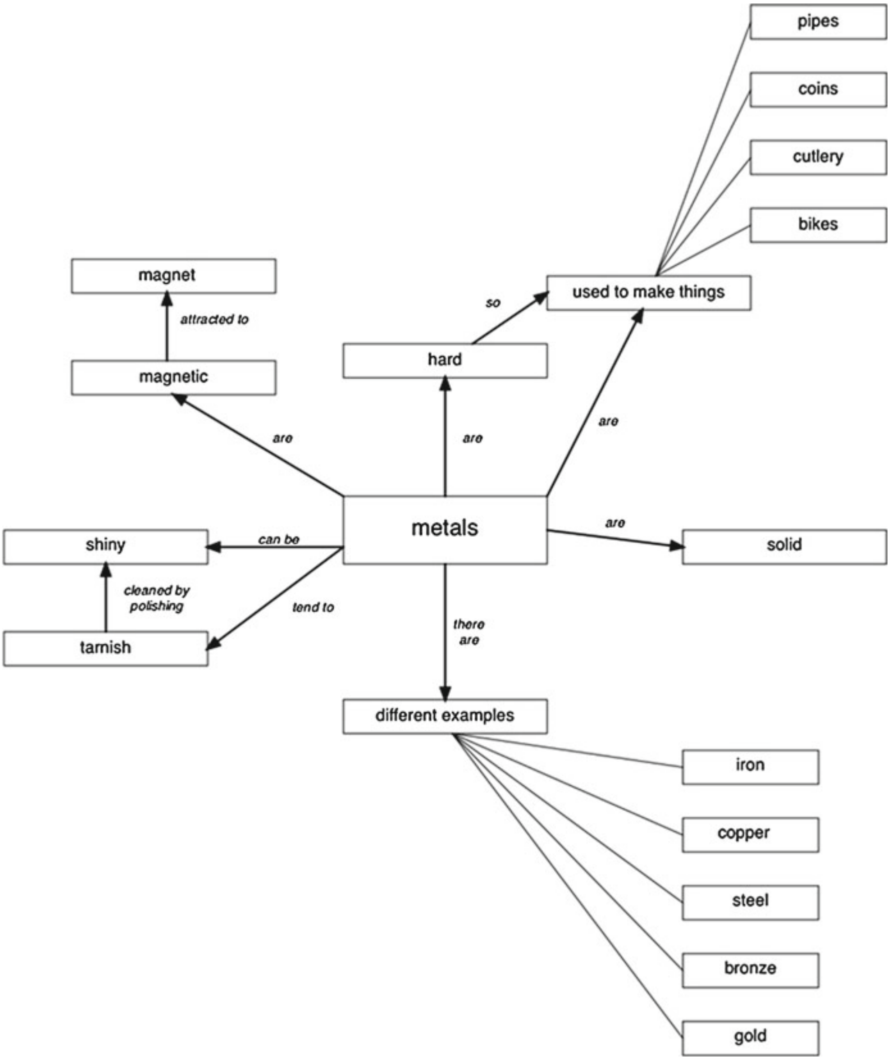

Fig. 15.4 Conception 1. Representation of a hypothetical pre-instruction conception of 'metal'

have acquired a concept of metal from a combination of their spontaneous experience of materials, and the tendency to find patterns in and categorise experience, and the way the term metal is used in lifeworld contexts. So an initially spontaneous concept will have acquired explicit representation in verbalisable form through exposure to many references to metal and to common examples of metals.

We would expect a young learner to typically consider metal to be a category of material, which includes some common types (iron, copper, etc.) and which has some common properties which are related to common uses of metals that are regularly experienced (such as coinage and knives). As a lifeworld concept, the notion of metal overlaps with, but is not entirely consistent with, the scientific concept.

So metals in everyday discourse are materials with certain useful properties that make them suitable for being formed into materials. So, for example, metals are hard and strong solids, allowing us to use them to make bridges that span rivers. It is also quite possible that our hypothetical learner will have acquired the common alternative conception that metals are (i.e. generally) magnetic (Hickey & Schibeci, 1999) in the sense that they 'stick' to a magnet.

When our learner meets the concept of metal formally in science class, they are likely to make sense of teaching about metals in terms of the pre-existing conception of metals. When the teacher refers to metals, this will be recognised as a reference to the types of materials the student already understands metals to be. Meaningful learning involves making sense of teaching in terms of existing conceptual structure, and references to metals will be interpreted through existing understanding of that concept.

Some modifications to existing conceptual structure can be seen as little more than additions to the existing conception, so Fig. 15.5 reflects that, for example, the learner may do some school practical work to show the electrical conductivity of metals – something commonly included in lower secondary courses. Probably, only a few examples will be investigated, but this is likely to be enough to acquire the generalisation that all metals conduct electricity, just as previous experience with magnets might have suggested that metals were generally magnetic.

Where new examples of metals are encountered either physically in the school laboratory (e.g. perhaps zinc) or mentioned by the teacher (e.g. perhaps manganese) these can be readily subsumed under the existing conception of metal – especially when they seem from the way they are discussed to fit the prototype of solid, hard materials useful for forming into structures. New properties of metals may be encountered, so, for example, our learner may be taught that metals have a property of being 'sonorous', which may be linked to new applications such as being formed into bells.

However, not all new learning can be fitted into existing conceptual structures so readily (see Fig. 15.6). The learner may be taught that actually most metals are not magnetic, and that only three common metals have this property: iron, nickel and cobalt. Indeed, if our learner sticks with the physical sciences long enough, this can change again when the magnetism concept expands to represent various forms of magnetism – paramagnetism, diamagnetism, antiferromagnetism – and it will transpire that the everyday notion of magnetism only refers to one type: ferromagnetism. At that point the magnetism concept would be some way removed from the simple notion of what a magnet can pick up.

Our hypothetical learner may also be taught that metals are considered a major category of the chemical elements. However, this may be accompanied by the start of a shift in the concept or perhaps a sense that the metal concept is ambiguous and has several foci; see below. So some of the examples of metals that were already familiar, such as steel and bronze, are not elements, but rather mixtures of elements and so perhaps not actually chemically metals, but something else: alloys. Our learner

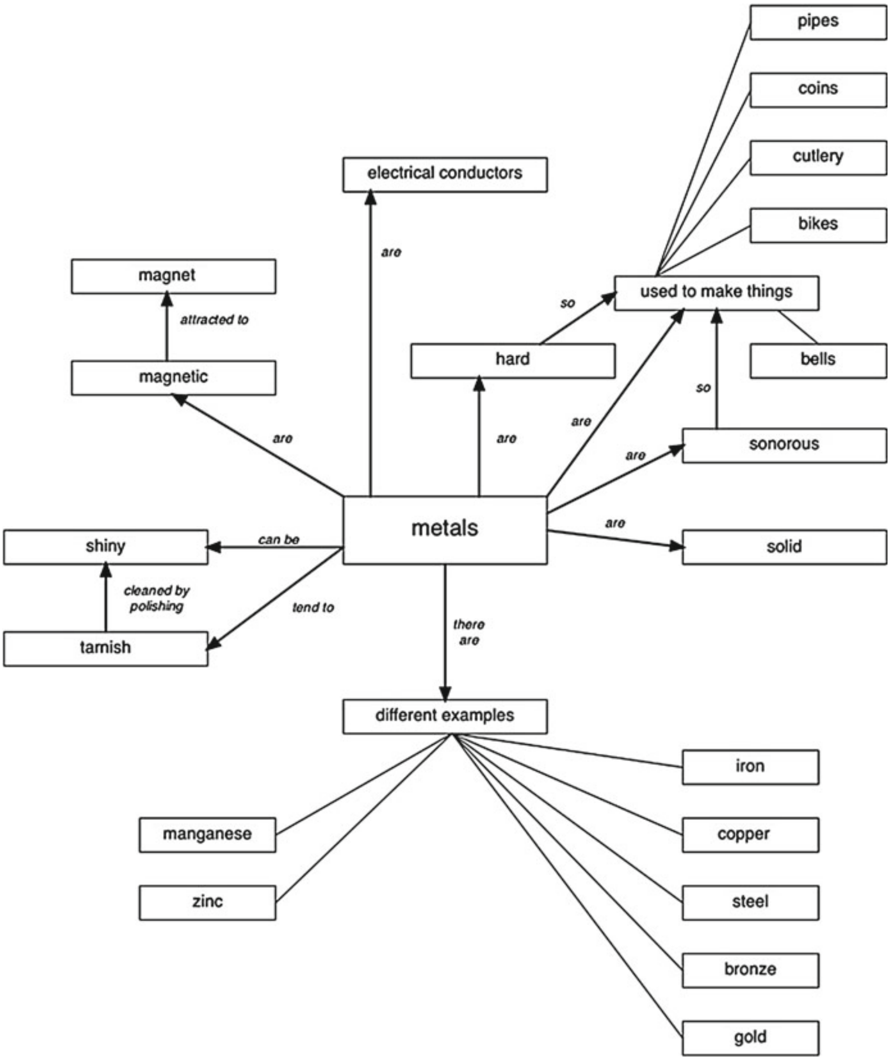

Fig. 15.5 Conception 2. Some new information may be assimilated by being subsumed into the existing structure – new examples, new properties

will also be taught about new examples of elements considered metals, which do not fit the stereotypical metallic properties – so sodium is a soft metal that reacts vigorously with water, and mercury is considered a metal whilst being a liquid at room temperature. This rather different, chemical, notion of the metal can undergo further development as study continues, as is suggested in Fig. 15.7.

So the primary properties of a metal *from a chemical perspective* relate not to its physical characteristics but its chemical behaviour: that is, to the nature of the

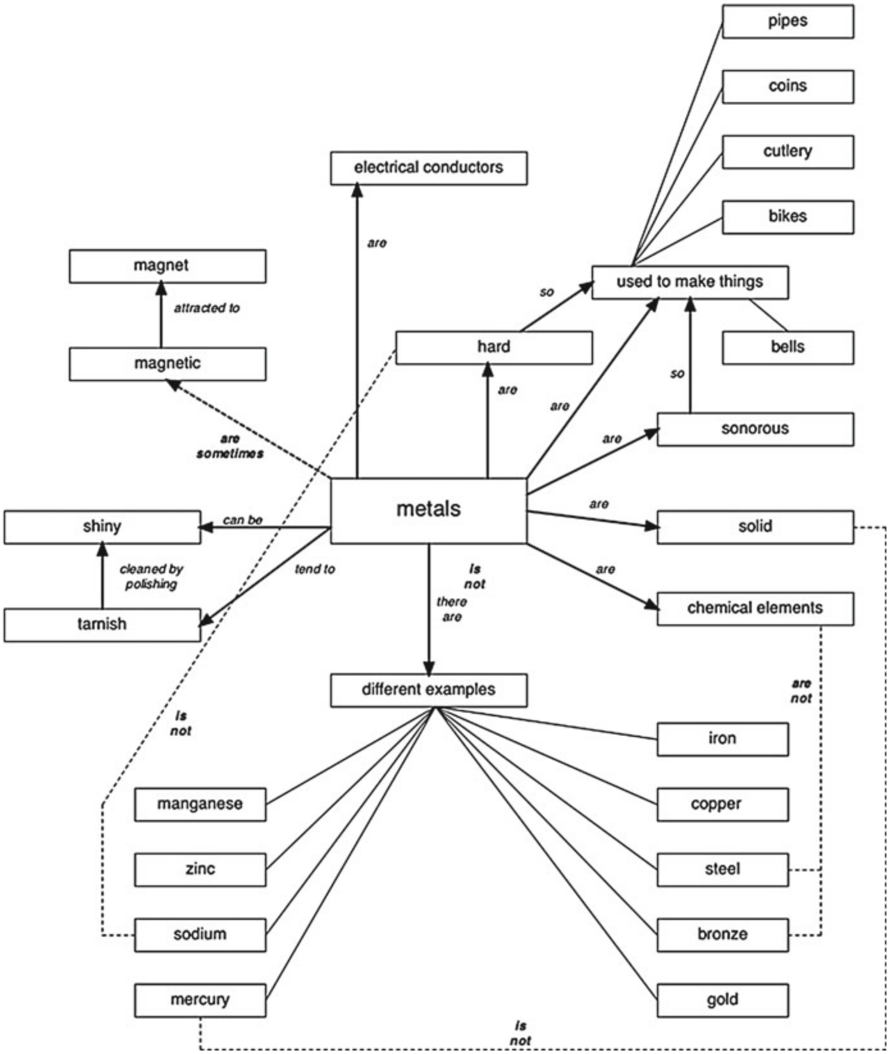

Fig. 15.6 Conception 3. Some new information assimilated into the structure may lead to inconsistencies with existing aspects of conceptual knowledge

reactions it undergoes. So the existing (lifeworld) notion that metals commonly tarnish will be related to a new idea that metallic elements may commonly be oxidised – and so linked to a more general chemical concept of oxidation. This will be accompanied by a shift in focus from how this affects the appearance of the metal to the nature of the product: an oxide that is basic or amphoteric, so potentially linking to developing concepts of acidity and alkalinity. Similarly, metals will produce salts when reacted with acids and will be classed as electropositive elements.

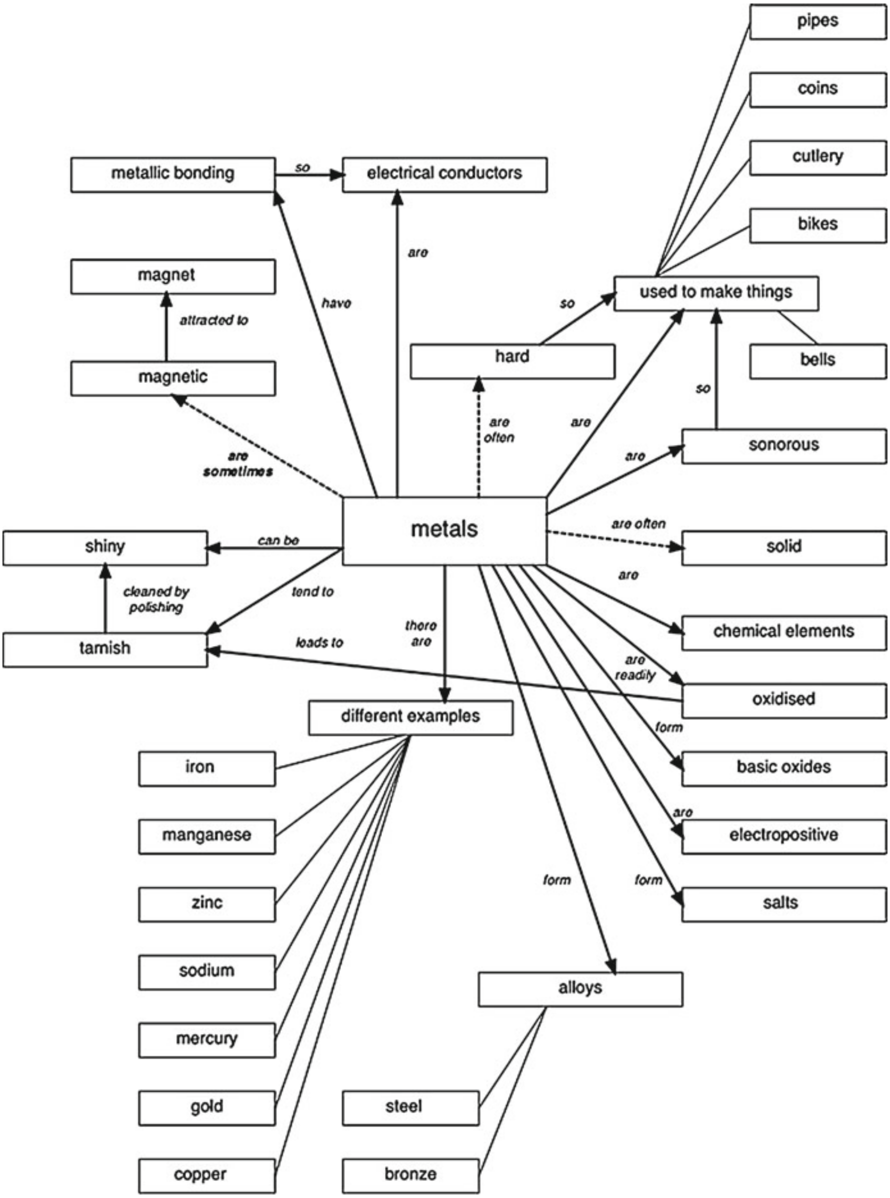

Fig. 15.7 Conception 4. Some new information assimilated into the structure may be accommodated by modifications of previous understanding and may offer potential for new linkages

This latter property may be explained in terms of submicroscopic models of atomic structure, which may also be used to characterise the crystalline structure of metals and the form of bonding found in metals. At this point our hypothetical learner's

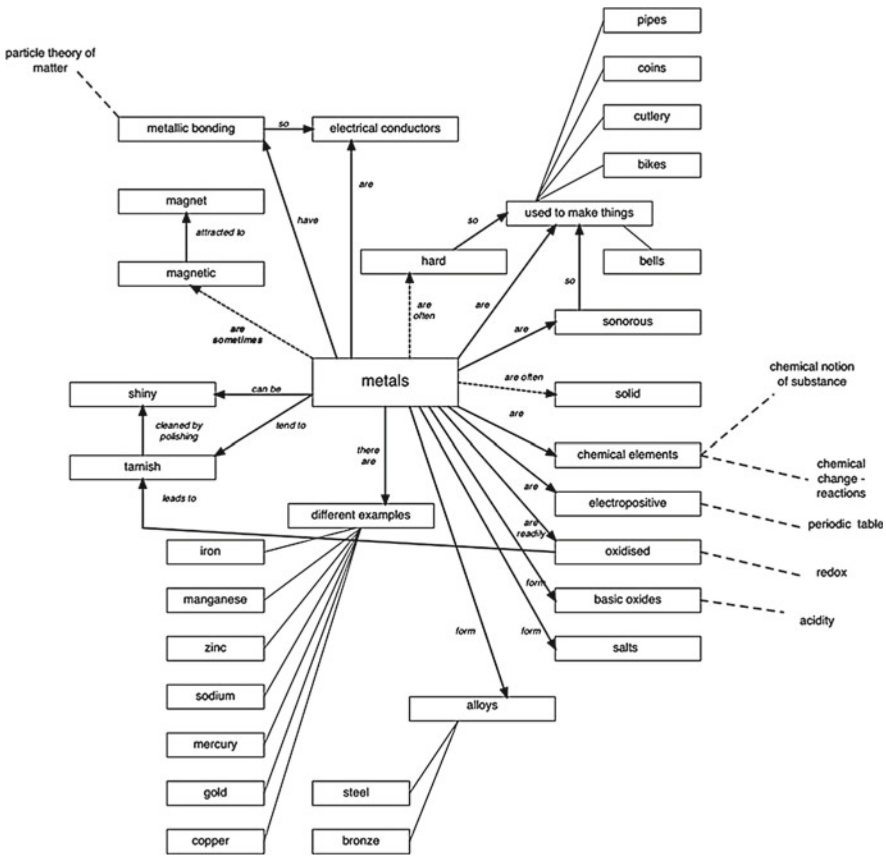

Fig. 15.8 Conception 5. Ongoing evolution of the concept within conceptual structure may lead to a shift in the nature of the concept (e.g. metal as everyday category to metal as a chemical category) and offer potential for extensive new linkage with other parts of conceptual structure

concept of a metal will have shifted quite considerably and will have become firmly embedded within a network of chemical concepts (see Fig. 15.8).

The Challenge of the Separate Domains Model to Conceptual Development

This form of representation (Figs. 15.4, 15.5, 15.6, 15.7 and 15.8), albeit here demonstrating a hypothetical case, seems to suggest that there *is a single conception* of metal that is evolving. Yet arguably this oversimplifies the nature of conceptual change. Caravita and Halldén (1994, p. 90) argue that 'organization, refinement and differentiation among contexts are other important and observable aspects which continuously enlarge the power of the system to perceive and interpret reality'. Commentators such as Solomon (1983) and Claxton (1993) have argued that systems of lifeworld concepts exist *alongside* formally taught concepts (see Chap. 12), with successful learners discriminating from context which set of concepts may be appropriate for particular discourse. Yet, if (as Vygotsky suggested) spontaneous concepts evolve with the learning of academic concepts, then arguably the initial spontaneous concept is no longer present as it has been modified through the construction of a hybridised, more developed, melded concept (cf. Fig. 15.3).

Solomon (1992), after detailed work looking at how children used the energy concept both in and outside formal school contexts, suggested that people maintain two separate systems of concepts. If that also applied across other topic areas such as metals, then they would be expected to retain a lifeworld notion of metal in one domain of conceptual structure, whilst building an alternative school chemistry concept of metal in a separate domain of academic concepts.

Energy is an abstract concept that is often understood by young people in quite different ways from the formal physics concept, because of the way the term is commonly used in social discourse – and the formal physics concept is somewhat counter-intuitive in that energy does not refer to anything directly observable but is used more like a formal accounting device (Feynman, Leighton, & Sands, 1963). In effect, Solomon's model suggests that there are synonymous energy terms and students are expected to use the context of any reference to know which energy concept is being referred to. So the learner is meant to appreciate that in the lifeworld context, a person can *raise* their energy levels by some moderate exercise, whereas in the physics classroom the same activity would be understood as a process of transfer of conserved energy *from* the chemical stores associated with blood sugar and oxygen through processes of working and heating the environment. Confusion might be best avoided here if these two ways of thinking and talking about energy are not considered to refer to 'the same thing'.

So whereas the simplistic conceptual change notion might suggest that school science should challenge an existing alternative concept of energy and seek to replace it by a more scientific conception, in the example of 'energy' there might be a good case for arguing that the role of school science is actually to help students form a distinct new (canonical scientific) energy concept, to be maintained in parallel with the existing lifeworld concept. The latter would be technically inadequate but arguably remains more useful in everyday social discourse.

Claxton (1986) has argued that given the difficulties in getting learners to shift from their pre-formal alternative conceptions of scientific ideas to new conceptions reflecting the scientific concepts, it is ineffective to try to start from their existing ideas and expect them to substantially modify these, and it might be better to look to build new concepts completely independently. In the case of energy, this seems a sensible suggestion: if we expect students to build the formal concept of energy from their existing lifeworld notion, then the task will be challenging.

In this case Vygotsky's notion of the spontaneous and academic concepts coming together is inevitably going to be problematic when 'lifeworld energy' can be gained by eating sweets and running around, and can be readily used up, and 'school physics energy' is never created nor destroyed. The logic of Solomon's research is that effective

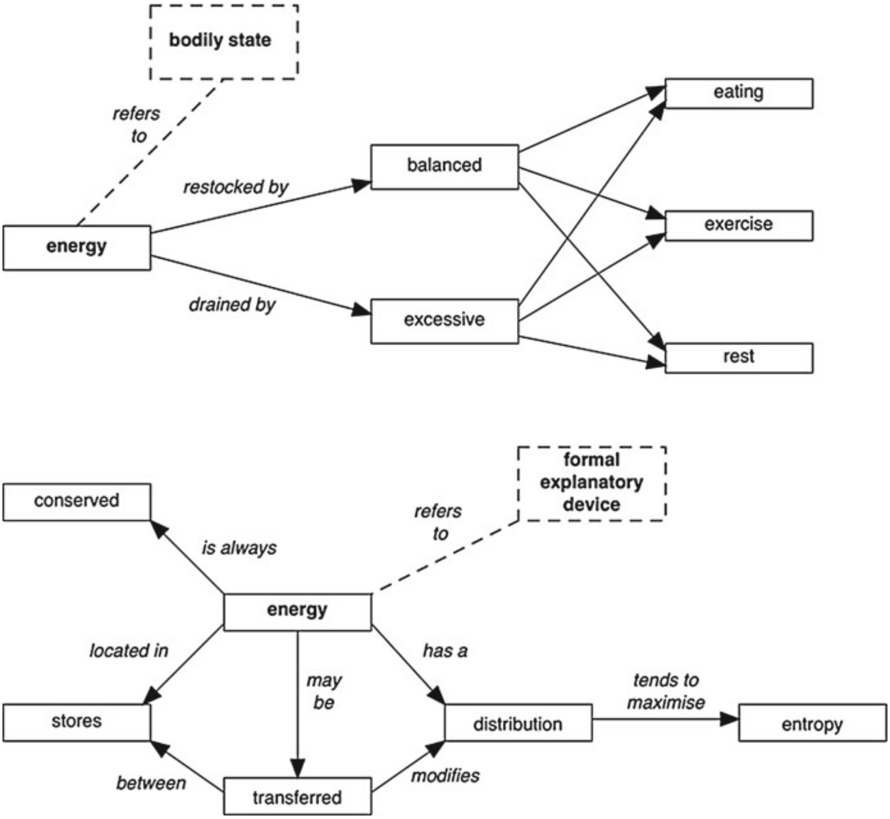

Fig. 15.9 The school science concept of energy (*bottom* scheme) is quite different in nature to the most common way the idea of energy is used in everyday discourse (*top* scheme)

students do create a new school science energy concept that they keep separated from their lifeworld concept and know when to use each in science classrooms and examinations versus in everyday discourse. By contrast, less successful students mistakenly attempt to make sense of school science tasks with their existing quite different lifeworld concept of energy. Arguably here, there is a good case for even avoiding the confusion of terms and basing teaching around free energy, given a suitable new label, rather than energy itself. As Fig. 15.9 suggests, the nature of these two concepts is quite different, as they have very different central concerns and core properties.

Multiple Conceptions or Manifold Conceptions

There is a significant challenge here for the research programme. In the case of energy, it seems the scientific concept is quite unlike the everyday notion, and Solomon's (1992) suggestion that conceptual development here is best understood as the formation of a new canonical energy concept in parallel to the existing lifeworld energy concept would seem credible and to avoid the issue of how people operate with a single energy concept which has quite different properties, and associated rules, depending upon context.

However, unlike in the case of energy, the lifeworld concept of a metal is not completely distinct from the formal chemical concept of metal – and indeed is quite close to how the term is commonly used in engineering contexts. There are many examples of metals – iron, copper, zinc, aluminium, etc. – that fit 'both' the lifeworld and the chemical use of the term. It seems much more credible here that the chemical concept of metal is not constructed separately from the everyday usage, but rather that the learner builds upon and modifies the spontaneous concept whilst learning the scientific nature of the concept.

This distinction would make sense in terms of the work of Chi and her colleagues (Chi, 1992, 2008; Chi & Slotta, 1993; Chi, Slotta, & de Leeuw, 1994). Chi has looked at student conceptual learning in terms of the way people build up their understanding of the ontology of the world. In particular, Chi has argued that such an ontology has distinct major trees of concepts and that a range of common learning difficulties in physics relate to students misidentifying scientific concepts that fundamentally refer to processes (e.g. heat) as material substances (Reiner, Slotta, Chi, & Resnick, 2000). So, for example, learners commonly think of heat more like the historical caloric (Cajori, 1922) than as a process of energy transfer due to temperature differences.

According to Chi, although conceptual change can bring about modest changes in the understanding of the nature of entities through modifications of a learner's ontological trees, it is not viable to switch a concept completely from one tree to another. So, for example, Chi would not think a student with a substance notion of heat can modify that to a process-based notion, but rather the learner would have to form the scientific concept of heat quite separately from any existing substance based notion. This ties in with Solomon's description of what happens in learning about energy in school and Claxton's prescriptions for avoiding attempts to build scientific concepts from students' own ideas where they are at odds with target knowledge.

From this perspective, teaching for conceptual development involves providing learners with alternatives to their existing concepts and supporting them to learn to access and apply the new school-learned concepts, rather than their prior conceptions, which remain unchanged. This will leave learners with multiple conceptions of energy, and heat, etc., each with different ranges of application. We might represent conceptual development in such as case as in Fig. 15.10 as an addition of a new concept.

If these two concepts are genuinely distinct, but just synonymous, then the context of a reference would be expected to activate one or other concept: just as references like 'Napoleon has been bringing home dead birds again' and 'Napoleon was an effective military leader' are likely to be recognised as referring to a family pet and a historical leader who share the same label. However, the example of developing the chemical concept of metal seems quite different, with the 'same' concept is incrementally modified over time. This would seem to be better represented by a scheme like that shown in Fig. 15.11.

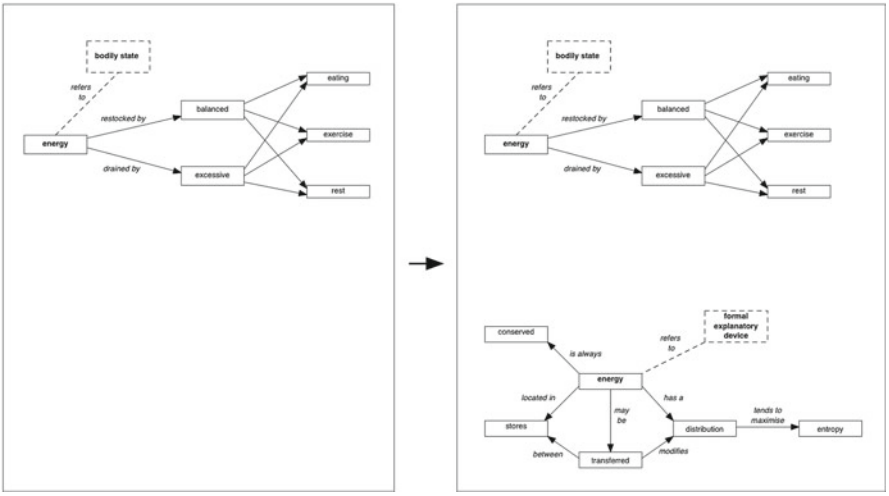

Fig. 15.10 Conceptual development of the scientific energy concept alongside a spontaneous concept (cf. Fig. 15.9)

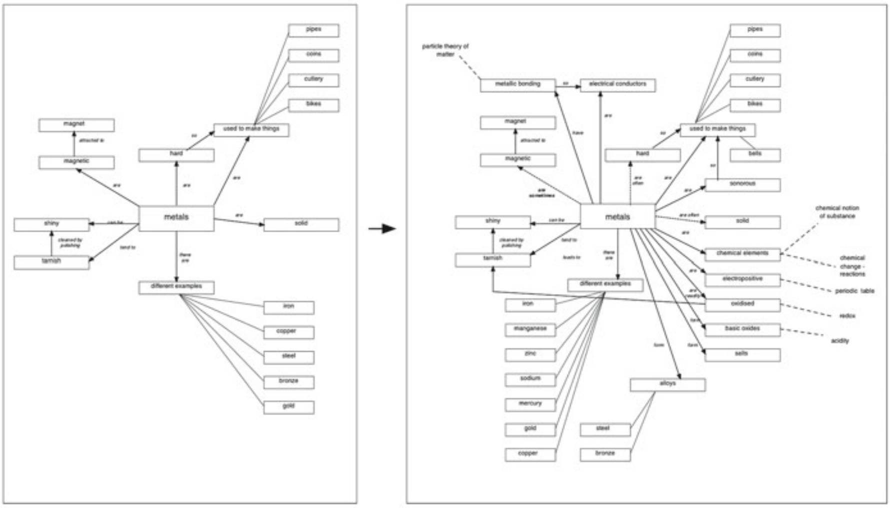

Fig. 15.11 Conceptual development of the scientific conceptions of metal (cf. Figs. 15.4–15.8)

In this case, our hypothetical learner will be able to work with a multifaceted metal concept, such that the term 'metal' can be understood differently in different contexts. So our learner will come to appreciate that, in the chemistry laboratory, sodium, potassium and mercury will be included in references to metals, but not say bronze or steel, whereas in the craft workshop the situation is reversed. Whilst it is simple enough to draw such figures, they do not explain how context provides the cues for different facets of the 'same' concept to be foregrounded in different circumstances. This presumably reflects extensive levels of interconnection between the different nodes of a figure such as Fig. 15.7, with various connection strengths, such that different patterns of activation across the concept become possible (such as in Fig. 15.12). This is an interesting area, but one which has not been explored within science education yet.

One promising idea that has been taken up for workers adopting a social constructivist perspective on teaching and learning concerns the notion of discourse practices. Although Solomon referred to different domains, an alternative way of understanding her findings is to think in terms instead of the different discourses that learners partake in. So it has been suggested that we all initially learn a particular discourse, with its norms and rules, in the home as infants. Later we enter other contexts, where new discourses become appropriate. From this context, learning progressions in school science involve switching from describing phenomena in terms of the 'home' discourse, to the more technical discourse of school science (Gunckel et al., 2012). The kind of cultural border crossing posited as a metaphor for learners entering the science classroom (Aikenhead, 1996) becomes a crossing into a different discourse community.

Multifaceted Conceptions in Science and Science Learning

The two examples of concept areas considered above, of energy and of metals, are quite different then in two important respects. The two energy concepts refer to different kinds of things, and have very different properties, and so it seems feasible that they may be quite distinct in cognitive structure as there is little basis for forming any coherent account drawing on both notions. The scientific metal concept refers to a material substance, just as the lifeworld notion does, and there is considerable overlap in how these two facets of the metal concept can be understood, including a range of common examples. In that case a melded hybrid concept incorporating both spontaneous and formally taught aspects seems more feasible.

The example met in Chap. 12 of a student having several different ways of thinking about chemical bonding (see Fig. 12.4) would at first sight seem to be an intermediate case: drawing upon both scientifically valid and alternative notions of the target concept. Yet, in practice it is much closer to a melded concept as the different narratives the student drew upon were, to his thinking at least, all based upon understanding of formally taught chemistry. These explanations were all offered in a discourse context of a student answering questions posed by a researcher who was also his teacher in the physical location of the college he attended. There is no lifeworld notion of chemical bonding, as the idea only has currency in academic settings, and although the idea that bonding forms so that atoms can fill their electron shells has no scientific validity, it was an interpretation of school learning and not an idea met outside of school science.

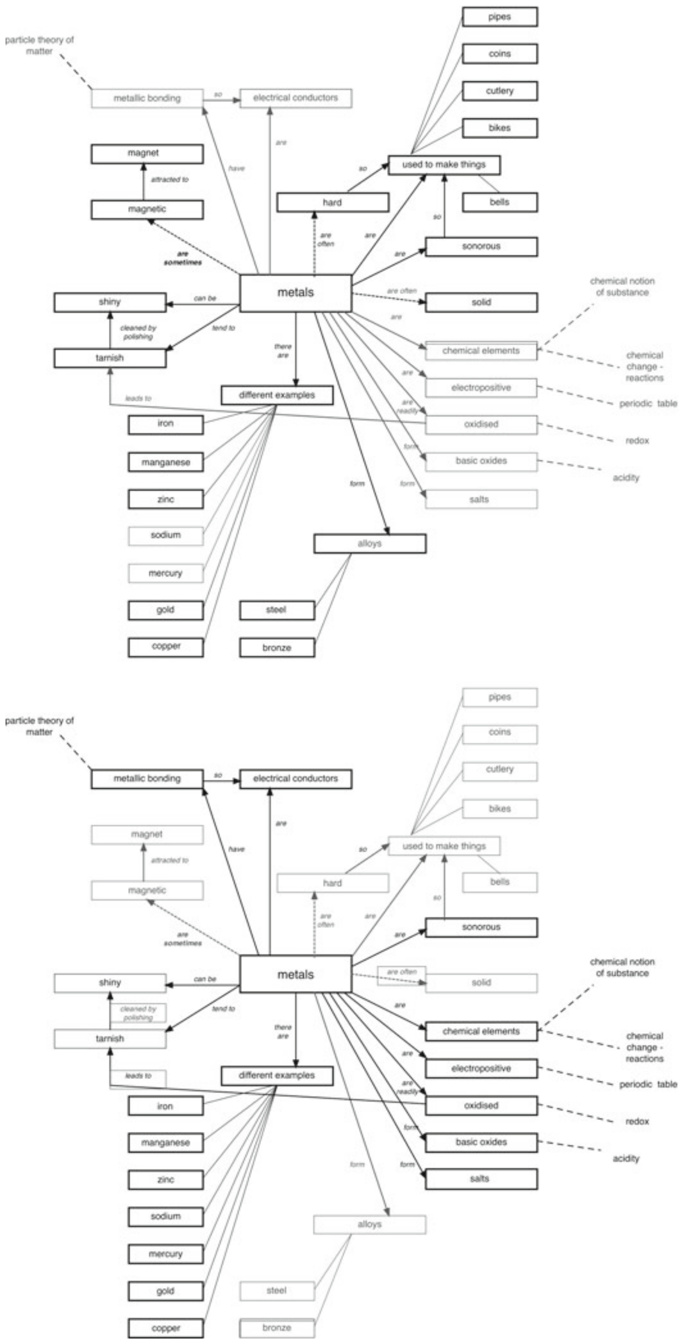

Fig. 15.12 Different patterns of activation of complex, multifaceted, conceptions (such as 'metal') seem to be triggered in different contexts

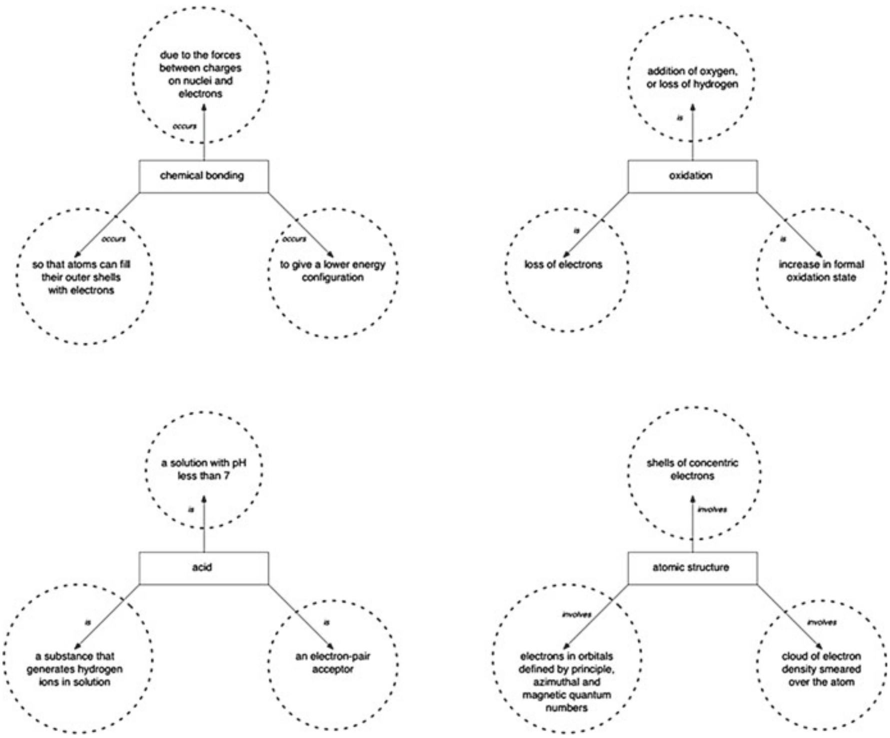

Fig. 15.13 Students' conceptions of chemical ideas may often be manifold

Whilst at first sight it might seem strange that a scientific concept taught in school could have such quite different manifestations, this is actually not so unlike a number of other concepts met in school and college chemistry. So the student of chemistry will meet sequences of definitions and models relating to such areas as acidity, oxidation and atomic structure. As with the student's multifaceted notion of chemical bonding discussed in Chap. 12, students are likely to develop conceptions in these other areas of chemistry which include inconsistent, alternative ways of understanding the concept due to the range of different models used in chemistry in these areas (see Fig. 15.13).

In three of the four cases the alternatives are all sanctioned within the curriculum and so are alternative conceptions of a scientific concept that are all in a sense canonical in they could be the 'right' answer in the context of certain questions that might be posed in the classroom. If we expect students to accept and distinguish between alternative scientific models for some scientific concepts met in their study, we should not be surprised if they develop a promiscuous conceptualisation of other concepts, especially when they consider they are adopting ideas presented in instruction.

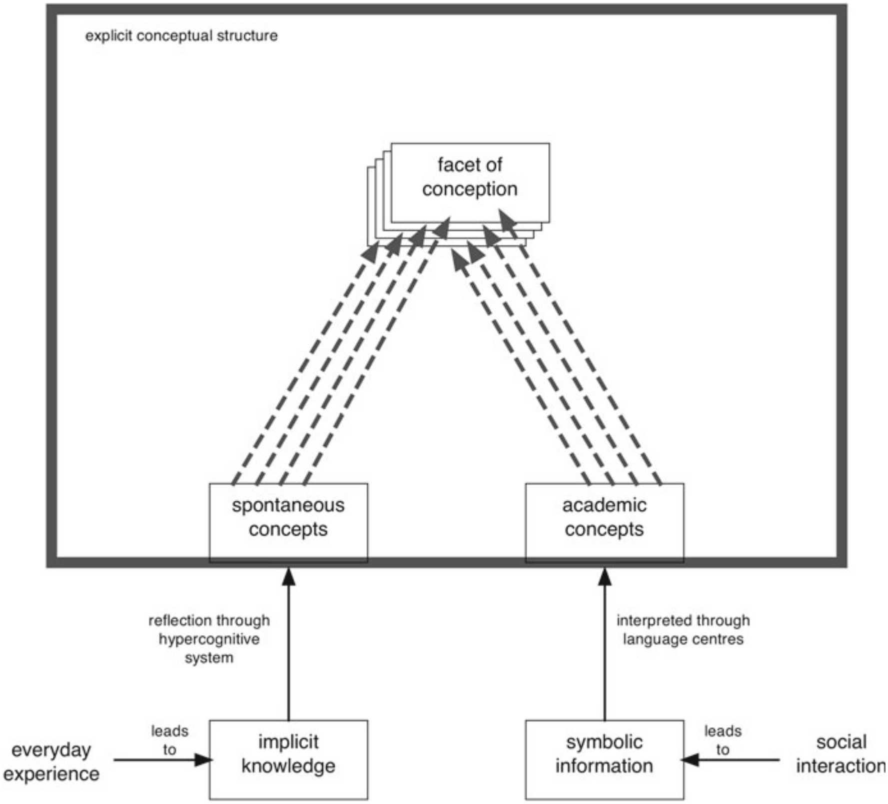

Fig. 15.14 Development of manifold conceptions

Petri and Niedderer (1998) explored one student's learning about atomic structure in a German physics class, as he, 'Carl', met different models of the atom. They concluded that

> Carl's statements in interviews, questionnaires and written tasks near the end of the instruction can be explained if we assume that the final state of Carl's cognitive system is an association of co-existing conceptions. To clarify, an association is when several conceptions co-exist and are connected to form different layers of the cognitive system, with a metacognitive layer on top. (Petri & Niedderer, 1998, p. 1083)

So Petri and Niedderer consider these different facets of a manifold conception to exist as distinct but connected 'layers' of the cognitive system. In Fig. 15.3 I have represented conceptual structure as a two-dimensional conceptual 'space', but Petri and Niedderer suggest an additional dimension is needed, allowing different facets of a complex concept to overlay each other.

This is reflected in Fig. 15.14, which suggests that each facet, or 'layer', of a manifold conception will draw upon both aspects of implicit knowledge and learning form others (e.g. teaching). Generally, different aspects of tacit knowledge may

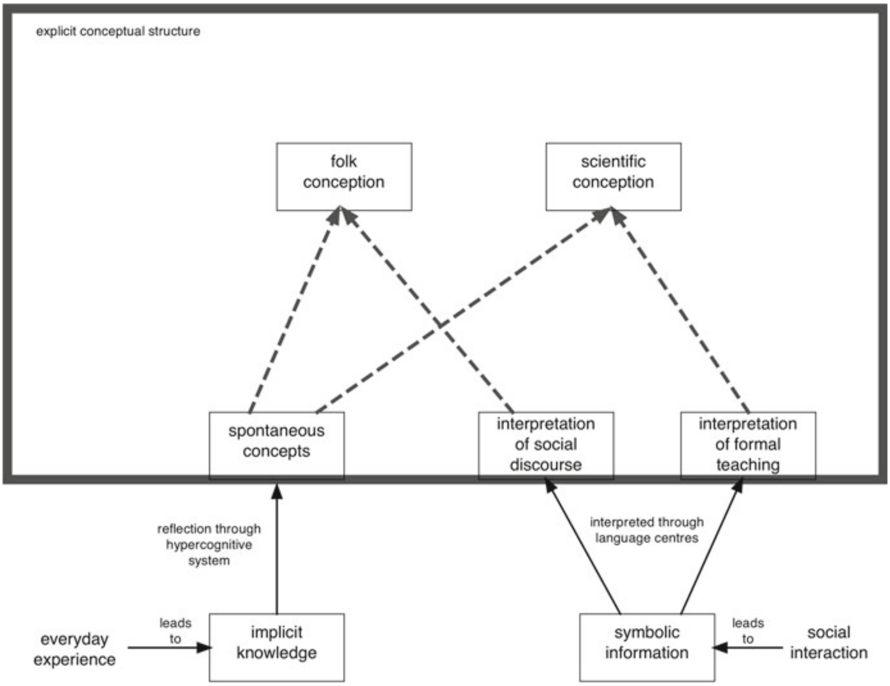

Fig. 15.15 Formation of discrete alternative conceptions

be drawn upon to provide the experiential basis of different facets. So, for example, it might be conjectured that the three facets of the acid concept suggested in Fig. 15.13 could possibly draw upon implicit knowledge (i.e. something like p-prims; see Chap. 11) related to extent (pH < 7), ejecting (generation of hydrogen ions) and engulfing or taking in (accepting electron pairs). This example is speculative, intended to illustrate the kinds of general patterns likely to be abstracted from experience at the level of phenomenological primitives. Establishing such links would be a matter for empirical research.

By comparison, the formation of distinct alternative conceptions, as suggested in the case of energy, whilst also drawing upon both linguistic information and implicit knowledge elements (e.g. relating perhaps to *balance* in one case and *conservation* in the other), would, it is suggested by Solomon's (1983) work, be represented quite separately in conceptual structure, as indicated in Fig. 15.15.

Revolutionary and Evolutionary Conceptual Change

It would seem we have three quite distinct models of how learners' conceptions of scientific concepts can develop. Vygotsky's argument that academic concepts draw upon spontaneous concepts allows the possibility of several largely independent conceptions developing in response to quite different discourses in different contexts and therefore being activated and applied in different contexts. So, arguably, for many learners, a conception of the folk world energy concept and a conception of the school science energy concept may be constructed largely independently.

However, much focus in science education (Taber, 2009b) and beyond (Vosniadou, 2008b) has explored how initially limited or 'alternative' student conceptions in science topics may be shifted towards canonical conceptualisations through teaching. Commonly a distinction has been made between evolutionary conceptual change and revolutionary conceptual change – although varying terminology has been used and some authors limit use of the term conceptual change for more abrupt, 'revolutionary', shifts. The simple models considered above can be related to this distinction.

So the hypothetical example of developing thinking about metals, discussed above, offers an example of an evolutionary conceptual change. Over a period of time, the learner's conception of metal shifts considerably (Fig. 15.11) but without any major discontinuities. New examples and properties are added without changing the basic type of thing that a metal is – a class of materials. Even though some previously accepted features have to be modified (as metals do not have to be solid, hard or magnetic), these modifications do not require a fundamental shift (as metal is still one type of stuff), and so we seem to be operating with the 'same' concept changing over time (whereas in the energy case we have added a whole new conception).

A more problematic case in many ways is how it is possible for learners to have revolutionary shifts in their conceptions: where they come to adopt a fundamentally different conception for the same target concept. Work on how to encourage such changes in learners has been the focus of much research and discussion in science education (Caravita & Halldén, 1994; Posner, Strike, Hewson, & Gertzog, 1982; Schwedes & Schmidt, 1992; Smith, 1991).

The ability to shift one's thinking between quite different conceptions of a topic has played a major role in the history of science and indeed was the basis of Kuhn's (1996) highly influential work on the 'structure' of scientific revolutions. However, inherent in that work was the assumption that even among professional scientists, such revolutionary 'changes of mind' were rare, with their spontaneous occurrence being limited to a few individuals. During so-called normal science most scientists adopt the canonical ideas of the field, supported by their induction into the disciplinary matrix through the discourses of the field. Science teachers are trying to encourage their students to adopt these canonical ideas, not make revolutionary breakthroughs in science by conceptualising the field in a more productive way than the rest of the scientific community. However, in some topics this may require a revolutionary shift from the students' current thinking.

Kuhn compared revolutionary insights to a paradigm shift, where a new pattern is recognised among familiar elements. In a sense that is what researchers recommending a knowledge-in-pieces approach (Hammer, 2000; Smith, diSessa, & Roschelle, 1993) to supporting conceptual change in students are looking to facilitate: that the teacher helps the learner construct new ways of understanding scientific concepts by building upon the most appropriate conceptual resources among the available implicit knowledge elements.

Thagard (1992) looked at this process of revolutionary change in scientific ideas from the perspective of explanatory coherence and suggested that such conceptual changes involved the construction of the new way of understanding the topic, in effect 'in the background', until a point was reached when the new way of thinking comes to make more sense, and fit more of the data, than the existing way of thinking. At that point the individual comes to consider the new way of thinking more fruitful and sets about persuading the field.

Arguably, representations such as Fig. 15.14 may be useful here, following Petri and Niedderer's (1998) metaphor of different layers of conceptual structure. Just as an individual might build up an 'association' of alternative ways of understanding concepts such as acidity and oxidation, and then *select* between them, so might they build up alternative conceptions of a target concept and over time *shift* between them. The suggestion is that in a revolutionary change, there is some kind of tipping point (Gilbert & Watts, 1983) where the balance of perceived strengths and limitations of two distinct conceptualisations switches to the new understanding being developed having more coherence, and this then becomes the preferred way of thinking about that target topic.

So whereas in the case of concepts which are understood in different ways (oxidation, acidity) we would expect the learner to retain the use of these different 'layers' as the different models are retained within science for different purposes, we can envisage how Lavoisier constructed his new understanding of chemical change as a new 'layer' 'over' the traditional phlogiston-based conceptualisation (Thagard, 1992), and over time came to consider the new conception (e.g. combustion is reaction with oxygen) as more fruitful than the traditional (e.g. combustion is release of phlogiston) conception. Using the visual metaphor of the representations in this chapter, making that comparison required Lavoisier to build his two conceptions as overlapping layers within conceptual structure allowing them to be directly compared (as in Fig. 15.14), rather than as discrete conceptions in different domains of conceptual structure (as in Fig. 15.9). However, it is important to keep in mind that figures such as those presented in this chapter only offer a schematic representation, a kind of spatial metaphor, as layers in the representational conceptual space do not relate directly to any obvious structural feature of the neurological substrate. The notion of layers may have much more to do with connectivity – how representations are associated through synaptic connections – than physical location in the brain.

Whether an individual retains manifold conceptions, or – in effect – shifts to a new conception leaving the earlier way of understanding in the background, but seldom activated, will presumably depend upon the extent to which the new way of thinking is found to make sense of all information and observations perceived as relevant to that target concept. During my study of the student discussed in Chap. 5, who developed his thinking about the nature of chemical bonding, there was the construction of new 'layers' within the 'association' (in Petri and Niedderer's terms) and a gradual shift in the extent to which the different layers were applied in discussing chemical phenomena. However, during that study, the original alternative conception never fell into disuse, although it ceased to dominate the learner's thinking across the range of application of the bonding concept (Taber, 2001b). It seems reasonable to consider this an incomplete learning pathway towards a revolutionary type of conceptual change: a revolution that was not completed during the two years of the learner's chemistry course.

When Is Revolutionary Change Required?

Given that revolutionary change is seen as so difficult to achieve, it must be questioned whether science teachers can reasonably be expected to encourage this type of change among their students. We have seen that Claxton (1986) has argued that often teachers would be better advised to avoid challenging existing conceptions and rather to seek to construct new conceptions to operate in parallel with their lifeworld understandings. This would make sense in those cases where Chi's (1992) work suggests the target knowledge is ontologically incompatible with the student' existing conceptions.

Watts and Pope (1982) suggested that it might to be useful to think about the learner's developing understanding of science topics as though the learner was working within a Lakatosian research programme (RP), and in the same year an influential paper about conceptual change made use of the idea implicitly (Posner et al., 1982, see below). For Lakatos (1970), a RP has a hard core of commitments, around which auxiliary theory is constructed. New evidence may lead to modification in the 'protective belt' of auxiliary theory, without challenging hard-core convictions. As long as new evidence can be accommodated within the programme, that is, without contradicting hard-core assumptions, then the learning trajectory will be shaped within that programme. If the core assumptions become seen as non-viable, then a new RP needs to be initiated built around new starting points (a different hard core); however, there is usually scope for reinterpreting new information within an RP using the malleable nature of the protective belt to insulate the hard core itself from the consequences of anomalies or counterexamples.

This seems a potentially productive way of thinking about student learning in science, although the perspective has seldom been taken up by science educators, that offers a useful perspective for making sense of some of the contrary claims in the literature as to whether students' ideas should be characterised as stable or readily modified (Taber, 2009b). Such an approach explains why learners are so resistant to change *some of* their ways of thinking. The kinds of ontological commitments that Chi (1992) suggested were so important would be strong contenders for hard-core assumptions of a student's personal RP. Perhaps the term personal *learning* programme, PLP, would be better in the context of individual learning. So a student who studies the physics of heating from within a PLP which has a hard commitment that heat is a kind of fluid is likely to make progress in learning – if not necessarily always quite the progress the teacher intends – as long as it is possible to interpret instruction in terms of heat as a fluid. For example, thermal conductivity could be understood in terms of how readily the heat fluid can pass through materials; temperature can be understood as a measure of the amount or concentration of the fluid in a particular place; and convection, conduction and radiation can be seen as means by which the fluid can get from one place to another. More detailed work is needed to explore how useful the PLP perspective might be in understanding student learning trajectories and in developing teaching to modify such trajectories.

In one study that has applied this perspective, Daniel Tan and I have suggested this may be a useful way of thinking about why research undertaken in Singapore found that graduates entering teaching as chemistry specialists showed similar levels of alternative conceptions (in the topic that was the focus of the study, ionisation energies) to the students they would be teaching, despite their opportunity to study the subject in depth in higher education (Taber & Tan, 2011). Presumably many of these new teachers had attended lectures, and read textbooks, and partaken in laboratory classes and tutorial and seminar sessions – but had managed to interpret a great deal of detailed information about their subject in line with the (alternative, non-canonical) hard-core assumptions about key chemical principles they brought from their own schooling.

The Notion of Conceptual Ecology

A basic premise of constructivist ideas in teaching is that the current state of a learners' cognitive system will influence the learning that takes place in the future. One aspect of the current state of the system is the actual available cognitive apparatus available to process new information – which might be said to depend upon the individual's level of cognitive development (see Chap. 13). However, just as important is the state of current knowledge as this provides the context in which new information can be interpreted and made sense of. I am using the term 'knowledge' here as suggested earlier in the book (in Chap. 9) to refer to what the learner believes to be the case or simply considers as a viable possibility: that is, the range of notions under current consideration as possibly reflecting some aspect of how the world is.

In essence the only alternative senses that can be made of teaching are those within the range of possible understandings of 'how the world is' available to the learner. Moreover, most commonly, we understand something we are told according to one out of those ways we have available to make sense of it, so normally the cognitive system will channel 'input' to activate some particular existing feature of conceptual structure that best seems to match the incoming information (cf. Chap. 4). In terms of the models being considered above, the context around what we hear or see will tend to cue activation of a particular conception: the folk conception of energy or the scientific conception, (Fig. 15.15), or a particular facet ('layer') of a manifold conception (Fig. 15.14). The context may be about 'who' and 'where' (children chatting in the playground versus the teacher presenting material formally in class) or more nuanced indicators. The teacher who asks how the students know whether something is an acid expects a different answer, based on a different facet of the acid concept, when she is dipping indicator paper into a solution in a flask, to when she is drawing ‘curly arrows’ on a symbolic representation of a reaction mechanism.

Posner et al. (1982) drew on the notion of ‘conceptual ecology’ (p. 214) and proposed conditions that need to be satisfied before major conceptual change (accommodation, in their account) could occur. They suggested four such conditions (p. 214):

1. There must be dissatisfaction with existing conceptions.
2. A new conception must be intelligible.
3. A new conception must appear initially plausible.
4. A new concept should suggest the possibility of a fruitful research programme.

The latter point relates to Lakatos’ ideas: Lakatos (1970) suggested that scientists should continue to work within a research programme even when its flaws were apparent, until there was an alternative which looked more promising.

Limitations of the Conceptual Ecology Metaphor

Posner, Strike, Hewson and Gertzog’s analysis was criticised by Pintrich, Marx and Boyle (1993) who argued that the strictly ‘rational’ basis for learning assumed by the Posner and colleagues model did not take into account the realities of the learning context in schools. Pintrich and colleagues argued that this approach ignored the way ‘individual students’ motivational beliefs may influence the process of conceptual change’ and how ‘individual learning in classrooms is not isolated but greatly influenced by peer and teacher’ (p. 172). Pintrich and colleagues suggested that the operation of the conditions identified by Posner and colleagues was constrained or enabled by various extra-conceptual issues, and they nominated ‘a range of theoretical entities in the field of motivational research that are possible candidates for incorporation in conceptual change theory and research’. In Fig. 15.16 the Pintrich et al. (1993) account is represented spatially as a set of terms of concentric circles.

Pintrich and colleagues argued that ‘motivational constructs such as goal orientation, values, efficacy beliefs, and control beliefs that can serve as mediators of this process of conceptual change’, and that students’ ‘intentions, goals, purposes, and beliefs’ would ‘influence the direction of thinking as the students attempt to adapt to the different constraints and demands placed on them by the tasks and activities they confront in classrooms’ (p. 192). Pintrich and colleagues also suggested that a student’s level of interest and the expectations implied by teaching styles and approaches would influence whether students would expect to process new information in any depth in a class and what they attend to in class. They suggested that the institutional and bureaucratic imperatives in schools may not always provide the

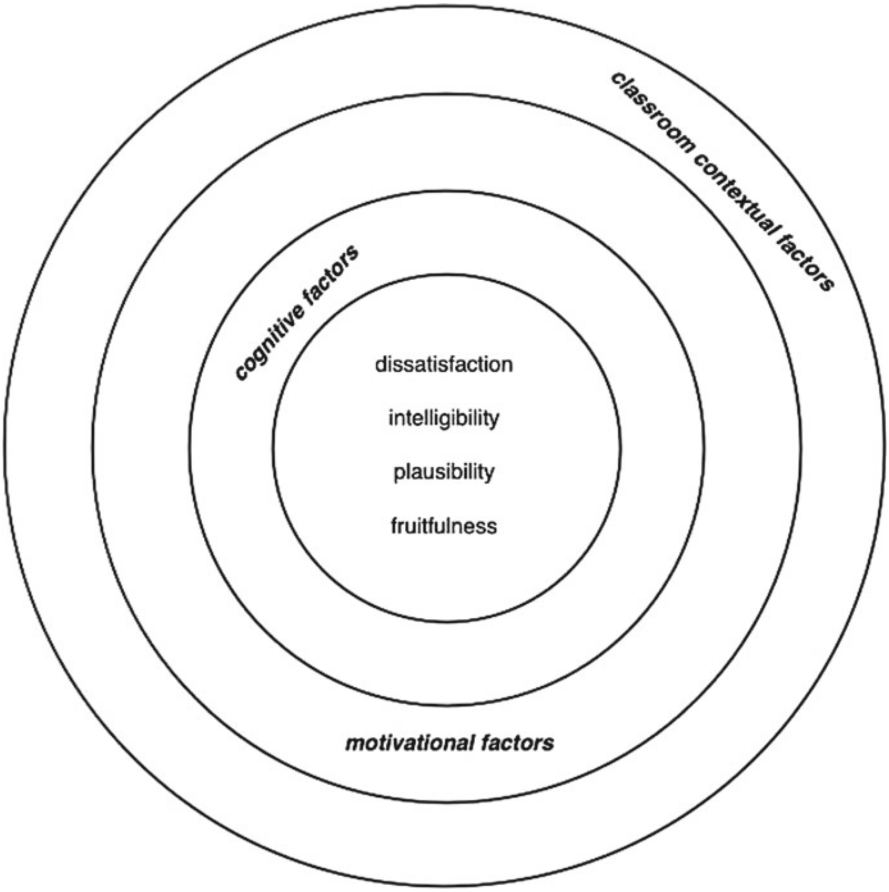

Fig. 15.16 Influences on conceptual change according to Pintrich et al. (1993)

environment for effective learning so that ‘even if some students approach school learning as intentional learners with a goal of developing integrated and sophisticated understanding of a field of study, they might not believe that the goals of the schooling enterprise are to foster such understanding’ (p. 193).

In effect, Pintrich and colleagues suggested that the factors identified by Posner and colleagues operate only to the extent that (a) the learner (i) has developed the necessary cognitive ability to apply them and (ii) has the motivational orientations for deep learning and (b) the institutional context offers norms and expectations that support this approach to learning (see Fig. 15.16). So whilst Pintrich and colleagues’ argument is seen to offer criticism of the Posner and colleagues model, it does not negate that model, but highlights how it is incomplete.

Posner and colleagues’ four conditions clearly refer to the way information is interpreted within a cognitive system, and as has been suggested earlier in this book

(Chap. 4) much information from the environment is not attended to and is filtered out before it reaches consciousness. It is not unknown for students in science classes to be thinking about 'something else', whilst the teacher is carefully setting out the arguments for accepting the scientific way of thinking about the topic of the lesson. It should also be borne in mind that although Posner and colleagues set out conceptual change as rational choice, the discussion earlier in this book suggests that need not mean explicit choice based on conscious reflection. It seems much of the cognitive processing that is involved in reaching such changes of mind takes place out of conscious awareness, although Pintrich and colleague would be right to point out that this is usually after periods of explicit consideration and exploration of the evidence that is being 'weighed'.

Figure 15.16 suggests that various factors filter, 'colour' and channel the information that will be 'weighed up' in such situations. As well as the norms and expectations of the classroom that might influence how study and learning is understood in that lesson, Pintrich, Marx and Boyle posit that such motivational factors as mastery goals, epistemic beliefs, personal interest, utility value, importance, self-efficacy and control beliefs will influence the level of student engagement with the material being presented. Where the student is engaged, Pintrich and colleagues list a range of cognitive processes/skills that will influence processing of available information, the 'data' in the system: selective attention, activation of prior knowledge, deeper processing (elaboration, organisation), problem-solving and finding, metacognitive evaluation and control and volitional control and regulation (p. 175). In effect, if the classroom conditions support deep engagement with learning, and if the learner is interested enough to be motivated to give full attention, and if the learner has developed the cognitive skills to be an effective learner, then the conditions for conceptual change may operate.

Pintrich and colleagues criticised the notion of the conceptual ecology because 'this metaphor is limited as a depiction of ontological change in learners in as much as learners are purposeful while ecosystems are not' (p. 192); however, arguably a learner's purposes are *emergent properties of their cognitive system*, partially responding to the learner-as-organism's inherent 'goals' which themselves are outcome of natural selection. As with much of the difference between Posner and colleagues and Pintrich and colleagues this seems to be a matter of how and where one focuses.

As an analogy, naturalists discussing the ecology of a particular habitat somewhere on earth would not normally feel the need to spell out much of the planetary-level context for what they are reporting. A hypothetical exobiologist from elsewhere in the galaxy might find it rather odd that such an account does not consider the rather significant factors of the radiation profile of our sun or the levels of oxygen in the earth's atmosphere. The exobiologist, perhaps having field experience of the ecosystems in many different planetary contexts, might feel these are rather major factors that have very important consequences for the biota in our focal habitat, and so consider it strange that they are not attended to. Yet, the earthbound naturalist who limits her reading to Earth-based journals might tend to assume that these factors can be considered as taken-for-granted background conditions.

Components of a Conceptual Ecology

In an earlier work I included a figure (Taber, 2009b, Figure 7.1) somewhat similar to Fig. 15.16 here, where I suggested that the individual conceptual ecology of a particular learner should be seen as nested within a series of other levels of context: a social environment roughly at the level of the classroom contextual factors in the Pintrich et al. (1993) model, within a cultural environment (the field of shared beliefs, values, norms, etc. in the society), within a natural environment (the biological constraints that shape the physiology and anatomy within which our cognition develops) and within a physical environment (which sets out the limits of what is possible in the universe).

Whether the cognitive and motivational levels of the Pintrich, Marx and Boyle model suggest there are missing components to that earlier representation depends upon what one includes within the scope of conceptual ecology. Posner and colleagues offered their own list of what might be important in influencing conceptual change (pp. 214–215):

- Anomalies
- Analogies and metaphors
- Epistemological commitments, including
  - Explanatory ideals
  - General views about the character of knowledge
- Metaphysical beliefs and concepts
  - Metaphysical beliefs about science
  - Metaphysical concepts of science
- Other knowledge
  - Knowledge in other fields
  - Competing concepts

Arguably the notion of a conceptual ecology can also encompass many of the factors Pintrich and colleagues considered at the cognitive and motivation level. The cognitive apparatus available to process the conceptual contents of a cognitive system is clearly highly relevant to how those concepts may be understood, related, compared, evaluated, etc. (see Chap. 13). Student interests and expectations about the nature of studying and learning, and what is expected and needed to function in the classroom, would all seem to be readily encompassed within conceptual ecology. For example, a belief that *learning in science class is about memorisation of material presented by the teacher* would be encompassed within the broad notion of knowledge used here. Similarly, a student view (whether explicit or not) that *studying science is unimportant and that minimal engagement in science classes saves valuable resources for thinking about more important things* is a judgement made in relation to that individual's overall conceptual structure. This will reflect prior learning about what is important and so should be valued, as acquired through prior experience and influenced by family, teachers, media, peers, etc.

So conceptual ecology is not just about what the learner thinks they know about the topic area under consideration, but also includes, inter alia, what they believe about their own learning abilities (generally or in that subject), what they believe about effective learning and what they believe about the importance of prioritising study in that subject over other competing demands on their attention. Pintrich and colleagues include notions about the nature of science as components of conceptual ecologies, and this might include features related to what might be termed 'scientific values' and 'scientific ways of thinking' (cf. Chap. 7). One particular aspect of an individual's way of making sense of the world that has attracted considerable attention in science education is what is known as worldview.

Worldviews, Scientific Attitudes and Religious Beliefs

Working as a scientist would seem to presuppose certain common values and assumptions (Kuhn, 1996): for example, the acceptance of some form of post-positivist position on the possibility of obtaining useful knowledge through systematic enquiry. Some would suggest there is a scientific 'worldview' that goes beyond this. Cobern describes a worldview as being 'about metaphysical levels antecedent to specific views that a person holds about natural phenomena' and providing 'the set of fundamental non rational presuppositions on which … conceptions of reality are grounded' (Cobern, 1994, p. 6). The position adopted here (developed in more detail in Taber, 2013e) is that scientists do not necessarily share the same worldview, but that scientists do share certain core commitments which would form *part of* their worldviews.

Arguably, (a) the consistency of the external world; (b) the presence of law-like regularities in that world; and (c) the possibility of obtaining viable knowledge of that world; can all be considered 'presuppositions' of science – principles that may then *seem* ratified by the findings of science itself. However, if this set of assumptions were to be viewed from a position that does not adopt such presuppositions, they might be considered tautological – as we interpret our observations in the light of these very presuppositions. Indeed, for most people with a scientific background, it is rather difficult to see how one could take a stance that does not include these particular assumptions about the world. A potential criticism of the scientific perspective is that its claims to knowledge rely upon metaphysical commitments (such as a–c), which are not in themselves open to genuine meaningful testing. Most readers of this book might wonder how it could be possible to live a structured, meaningful life in the world without taking for granted something like (a–c). These are assumptions that may well seem necessary and sensible, yet they are still a priori commitments. They inform our interpretation of experience rather than deriving from it.

Worldview has been described as a set of 'assumptions held by individuals and cultures about the physical and social universe… [including] the purpose or meaning of life' (Koltko-Rivera, 2006, pp. 309–310) or 'the principles and beliefs – including the epistemological and ontological underpinnings of those beliefs – which people have acquired to make sense of the world around them'

Table 15.1 Presuppositions of scientific and scientistic worldviews

Presuppositions	Worldview
The universe exhibits regularities reflecting some underlying stability (laws)	Scientific
Systematic enquiry into the world can bring knowledge that is in some sense valid (not necessarily 'absolute')	Scientific
All that exists is the physical world which can be probed by science	Scientistic
Science is the only approach which can provide genuine knowledge	Scientistic
Science can ultimately provide knowledge of all aspects of the world	Scientistic

(Kawagley, Norris-Tull, & Norris-Tull, 1998, p. 134). Certainly for some, there is considered to be a scientific worldview that goes beyond assumptions about the regularity and knowableness of the universe and encompasses more scienti*stic* assumptions such as:

- The physical universe is all there is (i.e. there is no *super*natural realm).
- The only type of worthwhile (or 'real' or 'true') human knowledge is that accessed by science.

And perhaps even that:

- All there is to know can one day be uncovered by science.

Clearly, holding such presuppositions can be very consistent with undertaking scientific work, but it is also clear that *not* holding these views need not undermine working in science (Taber, 2013e) – whereas, for example, not believing that the universe had some overall regularity to it would make scientific research, systematic enquiry into the natural world, rather pointless. These basic ideas, potential presuppositions of scientific work, are listed in Table 15.1. Whilst the first two principles would seem to be fundamental to all scientific work, the extent to which individual scientists adopt the final three will be much more variable.

A distinction that is sometimes made is between methodological materialism (which is about the assumptions necessary to do science) and metaphysical materialism (which is a broader assumption about the nature of the world). Methodological materialism does not allow supernatural causes and explanations to be introduced as part of science and is widely adopted by scientists. Metaphysical materialism goes beyond this and excludes the possibility of the supernatural completely – and is only adopted by some scientists. From this latter perspective, God or a spiritual realm is not only irrelevant to scientific explanation and argument but is necessarily rejected as a possibility (Taber, 2013f).

Some scientists exclude the possibility of there being any kind of God or other supernatural being and *consider this* to be part of their scientific approach to the world, whilst other scientists see no contradiction at all between undertaking scientific work and retaining a faith in a creator God who acts as a kind of 'ultimate' cause beyond the reach of science (Cray, Dawkins, & Collins, 2006). Indeed, many of the early pioneers of modern science were theists and did not see any need to exclude references to God from their scientific work given the cultural context in which they worked. Some other scientists are committed atheists but do not consider that their scientific colleagues need to share that commitment. Yet other scientists would consider the current evidence available about such matters as inconclusive and so would adopt the position that T. H. Huxley proposed as most suitable for scientists: agnosticism (Gilley & Loades, 1981; Lightman, 2002).

This would suggest that scientists do not all share a single scientific worldview but rather that there are different worldviews that have been found to be consistent with the necessary commitments for scientific work, even though *some* scientists argue that metaphysical materialism *should* be adopted as the basis of a scientific worldview (Taber, 2013e).

Worldview commitments provide a basic framework for making sense of the world which is not open to challenge – very much the 'hard core' of an individual's PLP (personal learning programme) in the terms discussed above. As everything is interpreted from the starting point of worldview, what is understood will not seem to contradict worldview commitments – and what others may suggest that seems contrary to worldview commitments may seem absurd. This is seen in debates about science and religion, with some scientists perfectly able to accommodate scientific work within a religious worldview, and indeed actually viewing all scientific knowledge within a theistic interpretation such that what science uncovers is how God maintains His creation through natural laws and mechanisms, whilst others seem incredulous at this, suggesting that any belief in the supernatural is inconsistent with a scientific attitude.

There have also been cases of devout scholars who whilst considering themselves scientists were able to dismiss widely accepted scientific ideas about the evolution of the universe and life on earth claiming that there was no real evidence for such ideas (Morris, 2000). Often this derives from worldview commitments to religious scripture as (a) the Word of God that (b) must be understood as offering a technically accurate account of the origins and history of the natural world, rather than offering theological truth sometimes presented through allusion, metaphor, myth, etc. This approach would not only be rejected by metaphysical materialists but also most theistic scientists who accept consensus scientific ideas about origins and believe that religious scriptures must be interpreted in the light of modern science, rather than scientific evidence needing to be fitted with a literal interpretation of scriptures.

However, in some educational contexts, many students do hold worldviews that are inconsistent with current scientific thinking about the origins of the universe and of life. For example, this has been a major issue in many parts of the USA (Long, 2011). In some Islamic countries, for example, Jordan (Dagher, 2009) and Oman (Ambusaidi & Al-Shuaili, 2009), science education is based on national curricula that explicitly reflect a theistic worldview. In National contexts such as these, students are actively taught that science reveals the wonders of God's creation.

Student Worldviews Inconsistent with Science Learning

This issue can be very significant for science educators. For some students learning science, it may not be just that they have acquired lifeworld conceptions at odds with scientific ideas but that the scientific ideas presented in the curriculum are contrary to fundamental commitments about how the world must be. So many learners in some parts of the world may enter the science classroom believing that all the main types of living thing are the products of special creation, that is, descended from ancestors created as complete organisms, in their modern form, and that the heavens are unchanging. If these are not simply incidentally acquired ideas, but derive from worldview commitments that are intrinsically tied in with issues of culture, community, identity, self-worth, etc., then these students will tend to interpret teaching in terms of such commitments. Where this is not possible then they will often reject the teaching.

It is not only students meeting scientific ideas from certain theistic worldviews (e.g. some Christian and Islamic perspectives) that may find some aspects of school science incongruous with existing commitments. Students from many indigenous populations are likely to find the reductionist, analytical approach of modern Western science at odds with holistic ways of understanding the world applied in their culture (Kawagley et al., 1998). The metaphor of 'border crossing' has been used to describe the process of entering into the culture of the science classroom. Aikenhead and Jegede (1999, p. 269) acknowledge that barriers to border crossing may be most severe among students from developing countries who find 'that school science is like a foreign culture to them' due to 'fundamental differences between the culture of Western science and their indigenous cultures'. However, they also suggest that 'many students in industrialised countries share this feeling of foreignness as well'.

Worldview as Conceptual Habitat

If conceptual ecology comprises of various components such as conceptions, analogies and epistemological belief, then to posit worldview as a component of conceptual ecology could seem to assign it no more status than an alternative conception or familiar image. This would not do justice to the influence of worldview.

This raises the issue of the nature of the conceptual ecology notion: that is, is it more than just a metaphor? The notion of conceptual ecology can be seen as a pedagogic device – as a means of drawing attention to how learning takes place in a complex context, with many potentially interacting factors influencing the learning process. However, it can also be seen as a form of model. This would require us to move beyond the metaphor (a reference to a non-specific similarity) to consider a formal analogy between conceptual ecology and biological ecology. Analogy allows learning by mapping between two parallel structures, from the more familiar to the less familiar (see Chap. 7). Teachers commonly use analogies to 'make the unfamiliar, familiar' as a means of using learners' existing knowledge as a basis for learning new concepts by identifying the structural similarities (Harrison & Treagust, 2006). In teaching, the teacher suggests an analogy and shows how to map from analogue to target. However, individuals can also explore potentially useful analogies for themselves, and analogical processes have been seen to be extremely important in the way scientists form new ideas (Nersessian, 2008).

In terms of the conceptual ecology notion, to refer to worldview as *a component* of a conceptual ecology is probably too weak a suggestion – where different components of the ecology may thrive or fall into disuse, the worldview will only shift, if at all, through a slow process of succession. Rather, then, in terms of the ecological analogy, the learner's worldview is akin to the habitat in which the conceptual ecology develops.

Once we adopt ecology as an analogy, we are in effect using a model, and in principle, a testable model. We might posit component features of the model that could lead to testable hypotheses:

- Concepts exist in a kind of ecology: they can take root, thrive or whither according to the environmental conditions.
- Some conceptions may be much better established than others.
- Conceptions may be in competition for the same niche in the ecology.
- Conceptual 'fitness' can only be judged in the context of the ecological conditions.
- A new conception requires a niche in which to become established.
- Worldviews offer very different habitats, suitable for rather different conceptions to thrive.

It is clearly possible to continue to develop such an analogy:

- The neonate offers a new habitat for conceptual development. In the biological case, a new habitat would have geological and physical conditions established, but no biota yet. By analogy, in the conceptual ecology, the child will have genetic predispositions, etc. but will not have formed any conceptions about the world.
- Change of worldview is a rare and potentially a major disruption of conceptual ecology akin to a major traumatic event (e.g. earthquake, flood), which disrupts an ecosystem and may allow very different succession of species.

One might suggests that the development of a particular conceptual habitat (worldview) will reflect the local (cultural) climate, and sometimes, for some learners, science lessons may seem like short periods of bad weather – (intellectual) storms at odd with more familiar climatic conditions and with potential to wreak havoc with the fine balance of the (conceptual) ecosystem. Conceptual ecology seems to offer many such opportunities for thinking about conceptual development in terms of the analogy with ecosystems. However, being able to suggest analogical mappings does not in any way assure that the conceptual case *is* like the ecological situation in useful ways. Rather, the analogy can be used as a creative device to suggest possible avenues for testing in research. Conceptual ecology is a fertile metaphor, but the extent to which it should be adopted – for example, as a way for teachers to think about their work – is a matter for empirical testing through res earch.