Chapter 6
Understanding the Mind

Many of the educational challenges that university students face fall into three groups: (a) normal learning (gaining new knowledge and learning how to solve certain kinds of problems in work situations), (b) conceptual change (changing some part of existing knowledge, in order to shift from everyday beliefs to expert-like understanding) and (c) transfer (how to apply and extend existing knowledge to deal with new contexts and new situations). Learning to become an expert practitioner, and to innovate, necessarily involves all three aspects: normal learning, conceptual change and transfer. What sort of cognitive system can provide a reasonably plausible explanation of how these processes occur?

Any account of professional knowledge work, learning and innovation has to involve a discussion of the human mind. The questions of how the mind functions, on what sorts of mental entities it operates, and how change and transfer occur, have been examined from a variety of theoretical perspectives in education and in studies of learning and expertise (Chi & Roscoe, 2002; Ohlsson, 2011; Sinatra & Pintrich, 2003; Vosniadou (2008/2013). In this chapter, we revisit these questions from the perspective of actionable knowledge by exploring three main themes.

First, in Sects. 6.1 and 6.2, we provide a synthesis of what are often seen as competing views on the nature of the human mind. We start by using Stellan Ohlsson's (2011) summary of the five main approaches to understanding the human mind. Ohlsson's goal is to show how four of these approaches fail to provide an account of the mind, because they 'escape' through various routes outside the cognitive mechanisms that are inside the mind. He aims to 'stop the leaks' and thereby show that a fifth – mentalistic – approach offers the best way to achieve a scientific understanding of mind. Our account inverts the logic of Ohlsson's 'stopping off' move: we argue that a comprehensive account of the mind entails following the ways it 'leaks'. That is, if we are to understand the mind in a way which is sufficiently comprehensive to support the design of professional education programs, then we should adopt a perspective that *integrates* these views rather than reinforcing firm boundaries and sharp oppositions.

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Second, in Sects. 6.3, 6.4, 6.5 and 6.6, we discuss some questions of conceptual knowledge and conceptual change, particularly as it pertains to knowledgeable action and professional learning. In Sect. 6.3, we review some debates surrounding the question of conceptual change, with a focus on relations between experiential knowledge and formal concepts. Our aim is to get at the questions of what changes in conceptual change and how this change happens, particularly when students learn conceptual knowledge that closely relates to their embodied experiences and professional actions. We then, in Sect. 6.4, extend this discussion to make connections with an area that has been very active in higher education research in the last decade – 'threshold concepts' and 'troublesome knowledge'. We show that this view, by attributing students' learning difficulties to their flawed mental models, creates an unproductive opposition between students' learning of formal articulated knowledge and their situated meaning-making. Section 6.5 revisits the relations between experience and conceptual knowledge by introducing the notion of 'situated concepts'. Drawing on contemporary cognitive literature, it proposes a rather different view of the human conceptual system and argues that much of conceptual knowledge is firmly grounded in situated human experiences of the world and support intelligent situated actions. Section 6.6 makes the next step and explores relationships between conceptual understanding and actionable knowledge.

Third, in Sects. 6.7 and 6.8, we address the question of transfer and learning for innovation.

6.1 Understanding the Human Mind and Learning: Experience, Brain, Environment and Culture

How does the human mind construct understanding? Ohlsson (2011) identifies five broad approaches in psychology that have tried, in different ways, to explain how the human mind works: phenomenological, neuropsychological, environmentalist, situated sociocultural and mentalist.[1]

The *phenomenological* tradition describes the mind as subjective experience – what one conceives, thinks and feels. The primary focus of such accounts of mind is human consciousness, thus how the mind operates and changes can be understood from the subjective experiences expressed in actions and discourse. While the phenomenologists acknowledge the limits of human consciousness – there is much more in human thinking, behaviour and feelings than a person can express – the key way to understand the mind is to depict those subjective phenomenological entities that present themselves in behaviour and discourse. Learning, from this perspective, involves increasing consciousness about the relationship between

[1] The descriptions of these five broad approaches, on this and the next few pages, are our summaries of Ohlsson's (2011) review and interpretation of each tradition. To each, we have added some extensions from other literature and some discussion of the implications of each approach for understanding learning.

oneself and the world, and change involves changes in human experience rather than in the mind:

> What it is that changes in conceptual change is the world perceived and the learner's capability of perceiving it. But these two things are actually two sides of the same thing: the experience of the world and the experienced world. (Marton & Pang, 2008, p. 542)

The *neuropsychological* account tries to understand the human mind by understanding the human brain. The focus is on those brain entities and processes that underpin human cognition, action, affect and other psychological processes. Neuropsychological accounts aim to explain human development and how the human mind operates by looking at the structures and regularities that can be observed at the physiological level, such as in the functioning of brain cells, the activation of neurons and the formation of synaptic connections. On this view, memory, learning and other cognitive processes are embedded in large networks of interconnected neurons that dynamically change their interconnections (Bransford, Brown, & Cocking, 1999; de Jong et al., 2009; Geake, 2009; Knowland & Thomas, 2014; OECD, 2007; Sousa, 2011). Over time, active connections are strengthened, while the inactive ones become weaker, increasingly tailoring the brain to fit the environment and producing a range of phenomena that underpin learning, change, expertise and skill development. From this perspective, learning and change are coupled with changes in the human brain's architecture, detectable by measuring brain activities at the neuropsychological level. On this view, knowing how the brain works allows one to set up appropriate conditions for learning:

> Guidance can be optimised by understanding the process of learning, the neurophysiological conditions that allow it and the changes that learning causes in the brain. (Knowland & Thomas, 2014, p. 101)

The *environmentalist* (or physically situated) accounts, in contrast, locate the agency and driving force for much of human behaviour *outside* the human skull – in the body and in the material environment. There are a number of different versions of the environmentalist view. For example, there are behaviourist accounts that see human behaviour and learning as a set of simple processes, coupling inputs from the environment (stimuli) with observable behaviours (responses) (Skinner, 1938). More complex accounts include the ecological approach to visual perception (Gibson, 1979) and embodied cognition and the extended mind (Anderson, 2003; Clark, 1999, 2012; Pecher & Zwaan, 2010). These see human action, perception and the body as fundamentally entangled with the material environment. The main assumption is that much of the information that accounts for human behaviour is located in the material environment. Then cognition that informs intelligent behaviour is underpinned by a human perceptual system that is responsible for aligning actions to the predictions derived from environmental regularities. Learning and change from this perspective are embodied in the very flexibility of human perception: an ability to sense the affordances of the environment and align actions and the body with the dynamically changing situation (Gibson & Pick, 2000; Smith, 2005). As Noë (2004) succinctly puts it,

> . . . perceiving is a way of acting. Perception is not something that happens to us, or in us. It is something we do. (Noë, 2004, p. 1)

Situated sociocultural (or socially situated) accounts look for patterns and processes that can describe human behaviour in the *social* environment and culture. This perspective ranges from accounts that say that much of what we think of as the human mind is based on internalised patterns of human social behaviour to more extreme formulations associated with situated cognition that generally assume no specific internal mechanisms are necessary to describe human behaviour (Cole, Engeström, & Vasquez, 1997). On this view, learning happens on an inter-psychological plane – by observing the behaviour of other people and by participating in communities of practice (Cole, 1996; Lave & Wenger, 1991; Rogoff & Lave, 1984; Scribner, 1997). In Jean Lave's (2012) words,

> . . . 'knowledge' or 'knowledge-ability' must be understood as part of, and as taking meaning from and for, persons engaged as apprentices to their own changing practice across the multiple contexts of their lives. (Lave, 2012, p. 167)

Finally, the *mentalist* view aims to provide an explicit account of what kind of system the mind is: what entities make it up, what kinds of processes it carries out and what kinds of transformations it undergo. Ohlsson explains this account by detailing a symbolic architecture of the mind. Cognitive functions, such as action, seeing, learning, memory, thought and decision-making, are implemented by a range of cognitive processes (Atkinson & Shiffrin, 1968; Newell & Simon, 1972). Mind, therefore, has a central 'control executive' that represents intentions or goals and coordinates all the other simultaneously occurring mental processes. The main entities on which the intellect operates are *mental representations*. Most mental activity is constituted by three discrete steps: perception, thinking and action. Cognitive processes, including learning, belong to the 'think' part of the mind. Much of the 'think' part operates on representations encoded in long-term memory, from where they are retrieved, on demand, into short-term memory in order to perform an action. Learning and change occur through two broad categories of change processes that can be labelled 'monotonic change' and 'non-monotonic' change (Chi & Ohlsson, 2005). Monotonic change proceeds in modest increments, without disruptive effects on current knowledge structures. Non-monotonic change involves significant re-representation, reconfiguration or replacement in the structure of the learner's knowledge (Chi & Roscoe, 2002; Ohlsson, 2009).

As Ohlsson (2011) notes, these five different approaches tell a story about different aspects of human behaviour and cognitive change. The phenomenological approaches describe, but do not explain, the human mind. They equate mind with consciousness and subjective experience. Ohlsson argues that, 'The process that produces those experiences – retrieval from long term memory – is not itself conscious' (p. 25) and thus cannot explain mental events. In trying to reduce mind to brain, neuroscience offers accounts that are overwhelmingly complex and fundamentally uninteresting (p. 26). The environmentalist approaches locate the forces shaping behaviour outside the person, in the environment. However, Ohlsson notes that behaviour does not emerge from the environment, but from an interaction between the situation and personal goals. The structure of the mind does not necessarily mirror the structure of the environment, and behaviour cannot be explained without assuming that there is 'significant internal processing' (p. 27). The situated sociocultural approaches try to explain human practices without reference to the mind, but as Ohlsson asks: 'How does the mind work, such that a person can create and participate in social and cultural systems?' (p. 28). He argues that questions about how communities and groups behave do not say much about how new practices are adopted by novices or how the mind works when a person creates and engages in new practices.

Ohlsson concludes that 'Mind cannot be reduced to conscious experience, the brain, the material environment or sociocultural factors' (loc. cit.) and argues that none of these four approaches answer the fundamental question of how the mind works: only the mentalist approach will do this. He acknowledges that all the approaches ask valid questions but that they replace the task of describing how the mind works with something else: subjective experience, the brain, the material environment or social factors. He sees these patterns and regularities as operating at different levels of the system and suggests that if one is serious about providing an account of how the mind works, one needs to close off these (purported) explanatory 'escape routes' to consciousness, brain, environment and culture.

We broadly agree with Ohlsson's analysis of the mentalist model. The attempts to model processes that take place solely in the mind have proven useful in many domains of learning and human performance, such as reasoning and problem-solving (Newell & Simon, 1972), creativity and practical intelligence (Sternberg, 1985) and working memory and instructional design (Sweller, van Merrienboer, & Paas, 1998). In general, the mentalist approach suggests that humans have relatively stable schemas, models or frameworks that represent structures, causal and logical relationships and processes in the social and material world (Schraw, 2006). Such schemas support human understanding of various phenomena in the world – classic examples from research on learning being: how the human blood circulation system works (Chi, De Leeuw, Chiu, & Lavancher, 1994; Chi & Roscoe, 2002), the shape of the earth and how the day–night cycle functions (Vosniadou & Brewer, 1994) and anticipating how events will unfold and how one should act in social situations, such as in a restaurant (Schank & Abelson, 1977). Mentalistically oriented accounts of human cognition can be quite successful at explaining the mental part of much everyday situated activity (Vera & Simon, 1993). Moreover, teaching and learning using abstractions can be a useful way of gaining important knowledge that supports understanding and skill (Anderson, Reder, & Simon, 1996).

However, *our attempt to understand the resourceful and fluent mind goes in the opposite direction to Ohlsson* – aiming to *open up* the routes between the mind and the places to which, Ohlsson complains, accounts of the mind usually escape. As Barsalou, Breazeal and Smith (2007) note, in real-world, real-time cognition, it is impossible to understand cognitive processes in isolation from other processes, such as perception, action and emotion.

> Indeed, understanding how a process coordinates with other processes may be as important, if not more important, than understanding the internal structure of the process itself. <...>

> [T]he coordinated relationships between perception, action and cognition must be identified to characterise cognition adequately. (Barsalou et al., 2007, pp. 80–81)

In our view, the human mind

- Is constructed, in significant part, via introspection (thus, can be informed by the phenomenological perspectives)
- Operates in a human organism that underpins and extends beyond the mind (thus, the brain perspectives)
- Is embodied and, therefore, responds to the material environment (thus, the environmentalist perspectives)
- Evolves in communities and other social groups (thus, the situated sociocultural perspectives)
- Is able to operate with various kinds of mental representations and intentions (thus, the mentalistic perspectives)

It is simply *necessary* to consider all of these together if we are serious about understanding the knowledge that produces the knowledgeable action of the human body and mind in the real world. A productive flexible mind is in fact conscious, embedded, embodied and runs on the brain and in culture(s). These different facets of human cognition are not just different layers of a complex system. They are interacting elements from which cognition emerges. Daniel Siegel (2012) puts it like this:

> A core aspect of the human mind is an embodied and relational process that regulates the flow of energy and information . . . the mind is a process that emerges from the distributed nervous system extending throughout the entire body, and also from the communication patterns that occur within relationships . . . human connections shape neural connections. (Siegel, 2012, p. 3)

One of the main functions of an intelligent mind is to be flexible enough to adapt and respond to changes in the other elements of the system, so that the overall performance of the system results in coordinated, fluent behaviour. To understand it, we need to understand all those elements and most importantly, what enables their interaction and fluent, mutual coordinated performance. In short, the human mind and practices change the body and the world, but the human body and the world change human practices and the mind.

Indeed, even those computer scientists and robotics engineers who are trying to create ‘intelligent machines’ are discovering the limitations of traditional mentalistic ways of tackling the question of human intelligence. It is no longer feasible to use models based on the idea of the mind as a ‘symbolic machine’ or a ‘brain in a box’, independent of bodily constraints, and depending upon explicit representations of the world (Brooks, 1991; Dreyfus, 1992, 2014). Real-world intelligence is intimately connected with real sensing and real action. As Brooks (1991) puts it:

> When we examine very simple level intelligence we find that explicit representations and models of the world simply get in the way. It turns out to be better to use the world as its own model. (Brooks, 1991, p. 139)

> . . . intelligence cannot be separated from the subjective experience of a body. (Brooks & Stein, 1994, p. 7)

We are not alone in feeling the need for a more integrative approach. A number of scholars interested in human development, learning and scientific and professional work have also found ways of going beyond traditional social vs. cognitive, mind vs. body and other such binary oppositions, producing their own adjustments and blends of different perspectives (see, e.g. Billett, 1996; Hutchins, 1995). Some of these approaches go under umbrella labels such as ‘cognitive ecology’ (Hutchins, 2010), ‘grounded cognition’ (Barsalou, 2008, 2010), ‘environmental perspectives’ (Nersessian, 2005) or ‘enaction’ (Stewart, Gapenne, & Paolo, 2010). Indeed, many other scholars who would consider their approaches, first and foremost, as anthropology, archaeology, sociology, linguistics, culture or philosophy are also providing fundamental insights into human behaviour, practice and mind (see, e.g. Boivin, 2008; Clark, 2011; Dreyfus, 2014; Ingold, 2011; Knorr-Cetina, 1999; Malafouris, 2013; Schatzki, Knorr-Cetina, & von Savigny, 2001; Sterelny, 2003, 2012; Szymanski & Whalen, 2011; Turnbull, 2000).

Much of our understanding of professional work and learning depends upon theoretical accounts in which the mind has a nontrivial role. The account of what mind is, how it contributes to intelligent performance, how it learns and can be taught and how it becomes capable of innovation all feature strongly. Our take, however, is a long way from the traditional mentalist view. It is not what many traditional cognitive psychologists would even regard as a ‘cognitive account’. First, perception, action, affect and other aspects of human behaviour that traditional symbolic accounts of intelligence regard as a noncognitive part of human behaviour have a *constitutive* role in our thinking (Barsalou et al., 2007). Second, knowledgeable action is embedded and embodied in material and social settings and practices. This material and social world is not just a landscape in which cognition and action take place, but is the provider of resources from which higher-level cognition is constructed and the terrain *through and in which this construction* takes place (Hutchins, 2010). People learn using conceptual and material tools, and within environments, that have been historically constructed. They construct their understanding creating new social arrangements and material artefacts in the same environment. The content of the mind, the shape of mental resources, in broad terms, is the result of active engagement and sense-making within a rich and complex culturally configured material and social world (Malafouris, 2013; McGann, De Jaegher, & Di Paolo, 2013; Sterelny, 2012; Stewart et al., 2010).

However, what kinds of cognitive mechanisms could support such ways of thinking and learning? We turn to this question next.

6.2 From Cognition as Structure to Cognition as Coordination and Enaction

Theories of cognition and learning commonly focus on the achievement of stable expert performance, but intelligent professional action requires flexibility across situations. Smith (2005) notes that one established way of explaining stability in behaviour across situations, or over time, is to look for stability in the mind and a single central unit that can coordinate all actions. A typical putative source for such stability is the notion of a *concept* or other such stable mental representations – such as theories, mental models, beliefs and frameworks – that can guide, but exist independently of, perception and action. In contrast, Smith argues that much of the apparent stability in human behaviour emerges from the variability and coupling of individual elements distributed across the mind, the body and the world. Smith provides a vivid illustration, using the movements of a cat. A cat's locomotion is an apparently stable pattern of alternating limb movements. But when the animal moves through uneven terrain, its movements cannot be explained by the existence of a stable central pattern generator that is capable of producing similar alternating movement of the four limbs. The variability in the movements is extraordinary and essential – each move requires very different muscle firings, to keep the general pattern of the limb alternation stable when the cat moves across real terrain – grass, rocks, undergrowth – backwards, forwards, quickly, stealthily, etc. Smith claims that this emergent and apparently stable behaviour can be accounted for by a *dynamic systems approach*. From this perspective, there is no one central control mechanism that has a causal priority – be it a stable concept, theory or plan. The apparently coherent pattern emerges from the interaction and self-organisation of many elements in the system. The overall behaviour of such a self-organised system can be characterised by a relative stability or instability, but this behaviour emerges from the coordinated relationships among the components, not from the stable workings of one central control unit.

In experiments, Smith demonstrated that such stable constructs as 'a concept of an object' are generally not necessary to explain stabilities in children's cognition. The intelligence is not locked into the cognitive system, but emerges in real time by coupling perception and action. The (human) cognitive system is neither stationary in its external behaviour nor in its internal processes. It has its own dynamics, and changes in this system are driven by its history and its activity in the world; it is a part of much larger systems and is flexible and capable of responding differently to different situations.

This view shifts the focus of what is central in knowledgeable performance from stable constructs that can control knowledgeable actions (e.g. concepts, theories) to constructs that are rich in relationships and interactions with other external and internal elements of the system and which are thereby flexible enough to produce coordinated and coherent performance of the overall system.

> The intelligence that makes alternating [cat's] leg movements is not strictly in the brain, not in the body, nor the world but in the interaction of a particularly structured body in a particularly structured world. (Smith, 2005, p. 286)

While Smith's example was primarily about the importance of outside systems in actions that seemingly don't place much demand on higher intelligence, she argues that 'Much of human intelligence resides in the interface between the body and the world' (loc. cit.). That is, people typically 'off-load' much of their intelligence to their environments:

> This off-loading in the interface between body and world appears a pervasive aspect of human cognition and may be critical to the development of higher-level cognitive functions or in the binding of mental contents that are separated in time. (loc. cit.)

Such everyday functions as remembering and counting are usually performed, at least in part, in the world rather than solely in the head. In short, what might seem to be a person's stable concept[2] is better seen as the outcome of fluid interaction among a variety of systems, of which the conscious mind is merely one.

Recent accounts of cognition, building on evidence from developmental research, robotics, neuropsychology and other domains, increasingly show that higher-level cognition (creativity, anticipation, intuition, decision-making, etc.) – often seen as vital in professional work and innovation – is not just a result of independent processes created by a modular mind. Rather, they emerge from interactions among many other basic systems in the brain, such as perception, goal management, action, motivation, emotions and learning (Barsalou et al., 2007; Damasio, 2012). In the past, many of these processes have been seen as either subsidiary or noncognitive. They have been treated as separable from the key higher-order cognitive operations that have been given such a dominant place in the mentalist approaches on which key instructional theories have been built. Yet they turn out to be inseparable from the very act of thinking.

So what *is* the role of concepts, theories and other organised mental constructs that have been such a focus in education's use of ideas on human cognition? The grounded cognition view suggests that mental representations (i.e. what one knows) have a central role in human thinking (Barsalou, 1999, 2009; Pecher & Zwaan, 2010). However, this cognitive system is unlikely to mirror the abstract, self-contained mental constructs, such as concepts or theories, that operate in a closed symbolic system. Cognition is embedded in the physical world, and this world is the main source of resources from which the conceptual system is constructed and organised. People, when they think about goal-directed performance, are 'conceptually there': 'The conceptualiser is in the representation' (Barsalou, 2009, p. 245) – making inferences about the perceptual information, actions, introspective states,

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[2] Or other such construct of higher-order cognition that putatively provides coherent guidance for their action.

perspectives and other aspects of the situation. When such situated information is not available, 'cognition suffers'.

Accounts of dynamic and grounded cognition do not say much about the nature and features of the cultural and material environments in which such coordinated performance becomes possible. However, there is a general acknowledgement that human cognition leans upon, and reflects, its social developmental processes. This includes the organisation of interactions, coordination and also interactions with material contexts that have themselves been shaped by social interactions (Smith & Gasser, 2005).

Some accounts of ecological cognition are helpful in this regard. As Hutchins (2010) asserts,

> For humans, the 'world' (in the now familiar 'brain-body-world' formulation) consists of culturally constructed social and material settings. <. . .> Human brain and human culture have coevolved. <. . .> Activity in the nervous system is linked to high level cognitive processes by way of embodied interaction with culturally organised material and social worlds. (Hutchins, 2010, pp. 711–712)

Social interactions are intimately involved in the learning of cognitively nontrivial social skills, such as working together.

> Humans probably learn important things more often through social interaction than they do from isolated individual interactions with inanimate stimuli. Furthermore, these socially acquired skills are intrinsic to coordinated activity in division-of-labour settings, and also in competitive activity in conflict situations. (Barsalou et al., 2007, p. 82)

Recent research in enactive psychology can help enrich and sharpen our understanding here (see, e.g. McGann et al., 2013). A distinguishing feature of the enactive approach is that the mind is not seen as located in, or a property of, an individual person. Rather, it emerges dynamically in the relationship between the individual and their physical and social surroundings (Varela, Thompson, & Rosch, 1991). This *engagement* – dynamic interaction between agent and environment – is central to the enactive view:

> . . . enactive psychology is more interested in the dynamics of coupling between an agent and its environment than the stipulation of the characteristics of either. The idea of coupling is quite simply the mutual influence between the agent and the environment from which emerges the meaningful behavior into which we are seeking insight. (McGann et al., 2013, p. 204)

This notion of coupling makes *skill* vital in enactive accounts: skill is what enables an agent to act successfully and reliably in an environment – but it is through a flexible kind of coupling:

> . . . in any given situation we are not merely reproducing previous patterns of behavior but *weaving* habitual actions into the details of the present situation . . . as we become more skilled our perceptions and actions shift. Our goals and intentions begin to operate in different ways . . . the coupling is of a different sort. The kind of meaning inherent in the activity is transformed . . . it is in the relations between the embodied, motivated and skillful autonomous agent and its complex [physical and social] environment that the meaning of the engagement inheres, and to lose sight of that relational description is to lose sight of psychology. (op. cit., pp. 205–206, emphasis added)

One of the key implications of the account we are using here is that perception and action become as important as, and inseparable from, higher-order cognitive processes in the mind. So the critical element of learning complex knowledge and cognitive skill is not the construction of decontextualised symbolic structures in the mind, but the *very coordination* of what is the mind and what is outside of it, including perception, action, embodied skill and other forms of engagement with the environment and with other people. If we believe in the power of what is usually called 'deep knowledge' underpinned by conceptual understanding in knowledgeable action, then the central question for professional education is as follows. How do we help students build the 'grammar' connecting those theoretical constructs onto their multimodal experiences of sensing and acting – the experiences on which human cognition naturally builds and operates. In short, the focus of higher-order learning shifts from abstracted knowledge (and conception, as it is classically understood) to knowledge that allows the coordination of conceptual thought with situated experiences (i.e. perceiving, acting).

Students' experiences of engaging with the world, including their natural everyday experiences, are therefore foundational resources for constructing conceptual understanding. In the next section, we provide an outline of some ideas that extend the account of mind in ways that are helpful for understanding professional work, knowledge and learning: looking more closely at relations between formal concepts and experiential knowledge.

6.3 Learning and Conceptual Change: Formal Concepts and Experiential Knowledge

Students' minds are not empty containers. Transmissionist views of how to teach, which reduce learning to a mere accumulation of new information and knowledge structures (also known as 'accretion'), have been extensively, and not unreasonably, criticised in the constructivist literature (e.g. Bereiter, 2002; Papert, 1980). Such criticisms have been widely aired in adult and higher education, including professional education (e.g. Barrows & Tamblyn, 1980; Boud & Feletti, 1997; Brookfield, 1986; Jarvis, 2012; Savin-Baden, 2000). We have no intention of rekindling the debate over whether direct instruction is better than other forms of teaching (Kirschner, Sweller, & Clark, 2006) – there is always 'a time for telling' (Schwartz & Bransford, 1998) and the important pedagogical questions have always been about how to structure and scaffold students' learning, rather than about how little one can get away with (Jonassen, 2011; Kapur, 2008; Kuhn, 2007). As we explained in Chap. 3, otherwise diverse accounts of professional knowledge agree on the fact that students need to know the key ideas, conceptual structures, procedures and strategies that constitute an important part of the knowledge base of their profession (Clark, 2008; Perkins & Salomon, 1989).

However, this is far from being the full story. The declarative knowledge that can be taught through direct instruction is not enough to guarantee successful performance (Ohlsson, 1995). Various exceptional intellectual traits, such as inspiration and creativity (Sternberg, 2004), and various other personal traits, such as mindfulness and responsiveness (Dall'Alba, 2009; Dall'Alba & Barnacle, 2007) or dispositions (Barnett, 2004), also play an important role in expert performance. However, an explanation of professional resourcefulness as solely an inborn capacity, or an inner state, provides very little guidance about the sorts of mental constructs and mechanisms that may underpin these capacities and how they may develop. From an educational point of view, this is not particularly useful. Middle-ground views of learning as a gradual enhancement, restructuring and refinement of knowledge, skills and innate traits tend to offer a reasonable account of what kinds of changes may explain students' progress from everyday common sense, to novice professionals, to experts (diSessa & Sherin, 1998; Hallden, Scheja, & Haglund, 2008; Meyer & Land, 2006; Wagner, 2010). Nevertheless, even in this camp, there are some very different views of how learning occurs and what kinds of instructional approaches might be productive. The core of this debate has evolved around the nature of students' 'uneducated' experiential, intuitive knowledge and what educators should do about that (diSessa, 2006). We elaborate on this debate as a part of our discussion of conceptual change and transfer later in the chapter, but for now we provide a brief overview of its main implications for learning. We outline two broad views on this matter, which can be labelled 'negative rationalism' and 'positive empiricism'. Boiled down to the common core, these views see students' prior experiential knowledge as either (a) unhelpful and best replaced or (b) useful in the right circumstances and suitable for building upon.

6.3.1 Negative Rationalism: Students' Experiential Knowledge Seen as a Problem to Be Overcome

Some scholars have noted that much of the constructivist research on expertise and learning has been adhering to a line of theorisation that can be characterised as a 'negative rationalism' (e.g. Hallden et al., 2008; Perry, 1965; Rommetveit, 1978). This perspective acknowledges that prior knowledge has an influential role in students' learning. However, students bring to schools and universities a range of 'naïve ideas' about scientific or professional phenomena. Some of these ideas are incomplete, but basically correct, thus their enhancement requires normal 'monotonic' learning or small repairs. In contrast, other naïve ideas contradict the normative conceptions of phenomena that expert communities hold and sometimes require radical 'non-monotonic' change (Chi & Ohlsson, 2005; Chi & Roscoe, 2002). For example, Chi and Roscoe (2002) show that correcting students' misconception that the human circulatory system is a 'single loop' rather than a 'double loop' involves just a simple repair of their mental models, which may be corrected by incrementally learning additional details and revising earlier beliefs. But other misconceptions, such as thinking about electricity as a substance, that is 'stored', 'flows' and 'leaks', rather than as a process, require an ontological 'non-monotonic' shift. Crucially, some naïve misconceptions can be both incorrect and robust, as they are tightly bound into rich explanatory frameworks, cultural theories or myths that are reinforced by naïve perceptual experiences and/or by social discourse. For this reason, non-monotonic change often depends on confronting students with alterative views and changing belief systems or theories fundamentally. As an example, Keselman, Kaufman and Patel (2004) found that students' understandings of HIV were often flawed, but not because the students reasoned using superficial biomedical knowledge. Rather, they drew on false, causally complex, cultural and experiential theories about the disease. Kaufman, Keselman and Patel (2008) then argued that only 'sufficiently robust and coherent' (p. 316) biomedical knowledge provides a sufficient basis for correcting lay people's 'flaws in the logic of the myths' (loc. cit.).

Perry (1965) noted that much of the literature on expertise takes a radically negative view of common-sense knowledge, seemingly regarding all early experiences as crude, primitive and opposed to higher-level expert understanding. As he sarcastically concluded,

> The first intelligent step to the handling of our experience is to supersede commonsense. (Perry, 1965, p. 126)

This negative view of common-sense knowledge and everyday experience features in many accounts of expert learning. As Ohlsson (2011) argues, deep expert learning requires one to 'abandon, override, reject, retract or suppress' knowledge that has been gained through direct, personal experiences (p. 21). Broadly stated, this 'negative rationalism' tradition tends to attribute many common learning difficulties to a combination of (a) the intrinsic difficulty of some ideas and (b) students' developmental challenges (Meyer & Land, 2005; Perkins, 2007; Vosniadou & Ioannides, 1998). It emphasises shortcomings in, and fallibility of, students' prior understandings: such as flawed conceptual models and other deficiencies in thinking.

6.3.2 Positive Empiricism: Students' Experiential Knowledge as a Productive Resource

Other scholars have proposed an alternative account of learning. They argue that the negative rationalism tradition has at least three major shortcomings: (a) it offers a misleading account of what intuitive knowledge is, (b) it significantly oversimplifies the nature of conceptual change, and (c) it underestimates the value of students' common-sense understandings and their abilities to reason in sensible ways (diSessa, 1993; Kirsh, 2009; Säljö, 1991; Wagner, 2006). From this perspective, students' common-sense conceptual knowledge and skills – which they develop through experience and use in solving day-to-day problems that they encounter – do not necessarily resemble the theories or other coherent constructs that are implicated in normative accounts of experts' understanding and reasoning or that are captured in textbooks. Rather, such experiential knowledge is less systematic and more tightly coupled with tools and other external affordances available for reasoning within specific contexts and situations. Yet this knowledge is not necessarily misleading and, overall, can be perfectly sufficient for dealing with problems encountered in day-to-day work and life. For example, Hoyles, Noss and Pozzi (2001) show that even expert nurses, during drug administration, use a range of strategies to calculate required dosages. Nurses' ways of performing these calculations are tied to specific drugs, quantities, volumes, packaging and other material affordances of the environment. They do not draw on a single canonical, taught method, but their strategies are sufficiently correct to get the job done efficiently and without mistakes (see also Scribner, 1985, 1997; Rogoff & Lave, 1984; Lave, 1988).

This positive empiricist account emphasises the potentiality, productivity and variability of intuitive conceptual resources and skills. From this perspective, students' experiential concepts and experts' normative concepts can be seen as different constructs, which do not compete for the same space in students' or experts' minds (diSessa & Wagner, 2005; Gupta, Hammer, & Redish, 2010). Rather than abandoning prior experience and trying to fit all knowledge into one normative discourse, the challenge is to find ways of paying attention to the relationships between tasks, contextual details and other aspects of the situation and drawing on intuitive resources when it is productive. As Säljö (1991) argues, any attempt to equate students' cognitive performances to domain-specific knowledge and preformed competences obscures how students' competencies actually develop. A more productive view is to focus 'on understanding the resources – mental as well as practical – that people draw on when solving problems' (p. 117).

These two perspectives provide a point of departure for rethinking the conceptual understanding that underpins actionable knowledge and how it develops. However, what kinds of cognitive structures and mechanisms underpin development of conceptual understanding? We now need to look more closely at how these two perspectives address the question of conceptual change.

6.3.3 Conceptual Change: Coherent Structures and Knowledge-in-Pieces

This central debate in the conceptual change literature is outlined by diSessa (2006). He draws parallels with a dispute about the nature of scientific knowledge and human understanding between Thomas Kuhn and Stephen Toulmin. With respect to conceptual change, the difference can be summarised as a concern for (a) the systematic replacement of students' misconceptions or (b) strengthening the appropriate activation of fine-grained mental resources (diSessa, 2006; diSessa & Sherin, 1998; Özdemir & Clark, 2007).

The coherent structures and misconceptions perspective broadly follows Kuhn's view. It starts from the assumption that students' initial intuitive understandings and/or incomplete understandings are critical barriers that block further learning. Thus, students' conceptual development mirrors stages of the history of scientific theories – in which deep and sudden restructuring of knowledge occurs at several different developmental stages and/or when students' incorrect yet coherent ideas are replaced by a correct theoretical understanding. Such changes can be seen as rational, and the conditions for progress are broadly similar to the conditions that have to be met for scientific revolutions. These include (a) the student's dissatisfaction with their existing conception and (b) availability of a new, intelligible, plausible and fruitful conception.

The fine-grained mental resources, or 'knowledge-in-pieces', perspective broadly mirrors Toulmin's ideas. On this view, the student's intuitive ideas are not expected to have much global coherence. Rather, as diSessa (1988, 1993) argues, these intuitive ideas are composed of hundreds if not thousands of small fine-grained elements that he calls 'phenomenological primitives' or 'p-prims'. These pieces of knowledge are formed through everyday encounters and experiences of various phenomena in the world – including social and physical phenomena (diSessa, 2000; Philip, 2011). They are generally very contextualised and loosely organised, rather than coherent paradigms or theories. P-prims nevertheless play productive roles in constructing a normative conceptual understanding and play generative roles even in expert reasoning (Gupta et al., 2010). Indeed, they provide the very ground for constructing such understanding. Rather than rejecting these intuitive resources, they should be recognised and rewired in a more systematic kind of 'conceptual machinery'.

The fundamental distinction between the two views concerns what kinds of entities are involved, how they are organised and how they change in conceptual change. diSessa (2006) argues that most theories of conceptual change see the human conceptual system as constituted of at least two nested levels: lower-level 'entities', such as individual concepts, and higher-level 'systems', such as theories, frameworks and ontologies. The coherence perspective generally assumes that the relations at a higher-level constrain entities at a lower level. On this view, it is hard, if not impossible, to achieve conceptual change gradually – without a fundamental shift at the higher level. For example, Chi (2005; see also Chi & Roscoe, 2002) argues that understanding of 'emerging processes' – such as 'diffusion', 'electricity', 'temperature' and 'evolution' – causes learning difficulties because the emerging processes are *ontologically* different from the 'direct processes', such as 'blood circulation', that are generally implied in everyday conceptions. Thus, correcting such misconceptions involves a conceptual shift between the direct and the emergent processes at a higher ontological level, before correct understanding of individual concepts, or formulation of correct propositions using those concepts (i.e. beliefs), becomes possible.

In contrast, the 'knowledge-in-pieces' perspective sees the relationships between different levels as generally weak and diverse (diSessa & Sherin, 1998). The main challenges that students face grasping complex conceptual ideas emerge from the need to coordinate many diverse situation-specific knowledge elements into an organised system. The difficulties involved in such conceptual change are not particularly distinct from those that learners face when they learn conceptually new knowledge, as it involves coordinating an overarching conceptual understanding with situation-specific understandings of the phenomenon. In this case, lower-level experiential entities provide the actual basis for a well-integrated conceptual understanding. Rather than correcting or 'repairing' beliefs or theories at a system level, one should focus on helping students to get and coordinate the multiple elements first. In short, early intuitive ideas do not need to be dismantled and replaced by abstract normative concepts nor need they be replaced by new, better, experiential ideas for learning to occur. Successful learning dynamically emerges from all accumulated experiences, thus progress primarily involves contextualising and establishing more systematic relationships between (a) learnt normative concepts and ways of reasoning and (b) students' existing ideas and ways of reasoning.

The ideas expressed in the positive account provide an opportunity to look more deeply into students' experiential knowledge and the mechanisms that underpin conceptual development and transfer. There is no need to see conceptual learning as an 'all or nothing' or 'all or something' (cf. diSessa, 2006; Marton & Pang, 2008) change in abstract, decontextualised cognitive structures. It does not need to be seen as learning that happens in and through just one or a few phases of sudden change, in which contextual details and experience are suppressed. Rather, it can be seen as *a gradual systematisation and coupling* of experiential understandings with normative constructs. Resources that constitute actionable knowledge emerge from the instrumental relationship between experience and formal ways of knowing. In order to make such connections, both have to be in place. Experience is not sufficient for conceptual understanding nor is conceptual understanding sufficient for successful action. An *emerging* relationship between the 'expert concepts' and students' 'everyday concepts' (which they naturally develop through experience and employ in action) offers a productive way of understanding how students develop functional and actionable knowledge.[3] In a nutshell, professional learning, at its core, needs to connect *knowledge* and *action* – it needs to connect 'expert concepts' and experiential 'everyday concepts' rather than break these links and impose new conceptual structures that operate independently from, and above, situated experiences of the world.

[3] Our use of the term 'functional knowledge' is inspired by Greeno's (2012) term 'functional concept'. We discuss this in more detail in Chap. 17.

6.3.4 Summary: What Changes in Conceptual Change?

In professional education, we need to be able to talk about conceptual knowledge, skill, action and change almost simultaneously so we need a reasonably good account of the kinds of entities on which 'change' operates. It is possible to align ideas in the conceptual change literature with the five perspectives on how the mind operates that we introduced in Sect. 6.1.

The *neurobiological* perspective associates learning with changes in the brain. Thus the main concern is related to direct biological mechanisms underpinning cognition. The main questions about change and transfer relate to the issue of brain plasticity, which is usually seen as a function of age, previous experiences, short-term memory and other partly biological and partly developmental factors. Age is often seen as related to lower levels of brain plasticity, yet it is generally acknowledged that the brain continues to be plastic and that highly complex skills can be developed throughout the lifespan (Knowland & Thomas, 2014). There is also increasing evidence that brain processes associated with higher-order cognitions are connected with brain processes associated with biological regulation of the body: indeed that the former emerge from the latter (Damasio, 2012). Overall, mind and body, rationality and emotion and other cognitive and noncognitive processes are increasingly seen as not only inseparable from each other but also from the environment and social others (Goleman, 2006; Siegel, 2012).

In contrast, the classic *mentalist* approaches tend to start from the assumption that the human mind is constituted of symbolic mental structures that are generally self-contained and relatively coherent. Thus, conceptual change typically involves the (complete) restructuring or replacement of one symbolic entity by another. The implication is that a person can see the world in one way or another, but not in two contradictory ways.

The *phenomenological* approaches primarily see conceptual change as evolving consciousness, thus the process may be more gradual – moving feature-by-feature or step-by-step towards an expanded awareness or greater sophistication. There may occasionally be more radical change, yet the relationship between externally observable behaviours and experiences and the mind is generally maintained through reflection, rather than abandoned.

The *sociocultural*, *situated and environmentalist* approaches tend to shift the locus of explanation away from the mind and towards interaction and context. They look for the sources of patterns in human behaviour, and for the causes of change, in the culture or in the environment rather than in the mind.

Those who are in the 'mind and consciousness' focussed camps inevitably have to provide an account of how one mental structure replaces an earlier incorrect (yet possibly coherent) structure constructed in a person's mind. That is, how a 'folk theory' is replaced by an expert-like theory. Those who are in the environmentalist or sociocultural camps generally do not need (or aim) to provide detailed explanations of what changes in conceptual change at an individual cognitive level:

changes come from, and can be observed and explained at, an external behavioural level – discourse or skill.

Within and across these broad camps, there is still some appreciable diversity in theoretical positions. Whether we look at the human mind, consciousness, discourse or action, we can find a range of approaches distributed along a continuum. At one pole, each aspect is seen as generally well structured and stable – resembling theories, models, beliefs and habits. At the other pole, things are seen as more fragmented and fluid – with a quality of being coordinated and assembled on the spot, on demand, from different elements. Even those theorists who see the mind as a representational device do not necessarily agree with the classical, rule-based, symbolic memory architecture – instead proposing other alternative more flexible and dynamic models of human conceptual thought, such as situated simulations, feedforward nets and other more connectionist mechanisms (for a review, see Barsalou, 2003).

The meaning of conceptual change then follows from an understanding of what has to be changed: (a) coherent structures and rules or (b) assemblies of diverse individual elements. So the debate about coherent structures vs. dynamic coupling and coordination, in relation to conceptual change (and transfer), thus cuts across accounts of brain, mind, consciousness, discourse, environment and body. Table 6.1 provides a succinct summary.

Table 6.1 Coherent structures vs. dynamic coupling views across the theoretical accounts of mind

	Knowledge is in the:	Coherent structures	Dynamic coupling
Neuropsychological	Brain	Nonconscious and conscious brain processes are discontinuous (for a review, see Damasio, 1994)	Nonconscious and conscious processes are highly interrelated (Damasio, 2012)
Mentalist	Mind	Symbolic memory architecture (Anderson, 1983)	Connectionist nets (Bereiter, 1991)
Phenomenological	Consciousness, experience	Beliefs, theories, mental models (Chi & Roscoe, 2002)	Knowledge in pieces and other mental resources (diSessa, 2008)
Situated sociocultural	Culture and discourse	Cultural models, codes, habits, routines (Holland & Quinn, 1987)	Interaction, shared meaning-making, sense-making (Engeström, 2008)
Environmentalist	Skilful perception, coordination of environment, body, action	Classical skill acquisition theories (Colley & Beech, 1989), behaviourism (Skinner, 1938)	Extended, embodied, embedded, enacted cognition (Clark, 2011)

6.4 Troublesome Knowledge and Threshold Concepts

While many psychologists, over the last three decades, have been looking for generic answers to educational challenges by studying students' higher-order cognitions, university educators themselves have looked more closely at the core of the disciplines, trying to find solutions to students' learning troubles that depend upon discipline-specific concepts (e.g. Land, Meyer, & Smith, 2008).

The idea of 'threshold concepts' is underpinned by an insight that there are certain kinds of 'hard to get', epistemologically tricky, knowledge that are essential to the disciplines and professions. As Land, Meyer, and Baillie (2010) put it:

> . . . the approach builds on the notion that there are certain concepts, or certain learning experiences, which resemble passing through a portal, from which a new perspective opens up, allowing things formerly not perceived to come into view. This permits a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something, without which the learner cannot progress, and results in a reformulation of the learners' frame of meaning. The thresholds approach also emphasises the importance of disciplinary contexts. As a consequence of comprehending a threshold concept there may thus be a transformed internal view of subject matter, subject landscape, or even world view. (Land et al., 2010, p. ix)

Imagery relating to gateways, portals, thresholds and *liminality* (from the Latin for 'threshold') is widely used in this area of literature, within which threshold concepts are said to be:

Transformative: once understood, a threshold concept changes the way in which people see the subject. That is, such understanding results in a shift in their perspective, and perhaps even their values.

Irreversible: once understood, a threshold concept is not likely to be forgotten; it will be difficult to 'unlearn'.

Integrative: threshold concepts are likely to bring together different aspects of the subject that previously did not appear to be related.

Bounded: these concepts delineate a particular conceptual space and serve a specific purpose; they do not necessarily have a meaning beyond the specific discipline.

Troublesome: they can be troublesome for a number of reasons, which we explain below.

Threshold concepts are distinct from what university teachers describe as 'core concepts' – the traditionally acknowledged conceptual 'building blocks' that allow progress in understanding of the subject. These building blocks are essential, but they do not *necessarily* lead to a *conceptually different* view of the subject, and not all of them are troublesome. Threshold concepts, in contrast, are associated with certain deep learning difficulties and their learning involves 'transformation'.

The process of transformation generally includes three modes: preliminal, liminal and postliminal (Meyer, Land & Baillie, 2010). In the *preliminal* mode, students encounter the troublesome knowledge inherent in the threshold concept which instigates the transformation. This is followed by the *liminal* mode, in which students integrate new, and discard previous, understandings and undergo an ontological and epistemic shift. In this state, as Meyer et al. (2010) put it, 'an integration of new knowledge occurs which requires a reconfiguring of the learner's prior conceptual schema and a *letting go* or *discarding of any* earlier conceptual stance' (p. xi, emphasis added). The effects of this transformation are consequential. Thus, in the final *postliminal* mode, once learners cross the conceptual boundary, the transformation becomes irreversible and evident in changes in their thinking and discourse. Throughout this transformation process, students encounter a fourth *subliminal* mode, in which they start to recognise and understand the 'tacit underlying game' that underpins troublesome knowledge. As Land and Meyer (2010) say,

> There is variation in the extent of students' awareness and understanding of an underlying game or episteme – a 'way of knowing' – which may be a crucial determinant of progression (epistemological and ontological) within a conceptual domain. Such *tacit understanding or epistemic fluency* might develop in the absence of any formalised knowledge of the concept itself; it might for the learner represent a non-specialist way of thinking. (Land & Meyer, 2010, p. 64, emphasis added)

While this underlying way of knowing and epistemic fluency is considered to be critical, the subliminal mode is seen as a *tacit* mode, where changes just gradually happen:

> In what we might term the 'subliminal' mode, there is often an 'underlying game' in which ways of thinking and practising that are often left tacit come to be recognised, grappled with and gradually understood. (Meyer et al., 2010, p. xi)

The whole transformational process may involve some recursiveness and oscillation around the previous understanding, but generally such 'grappling' is considered to be a temporary 'perspective transformation' state. The transformation involves social repositioning of the learner; thus adopting the specialised expert discourse is seen as no less important than developing the conception. Meyer and Land (2005) emphasise

> ... the interrelatedness of the learner's identity with thinking and language. Threshold concepts lead not only to transformed thought but to a transfiguration of identity and adoption of an extended discourse. (Meyer & Land, 2005, p. 375)

The threshold concept perspective generally underscores the revolutionary nature of such transformations and the replacement of previous concepts and understandings with completely different views. 'The prevailing perception has to be let go of and eventually discarded so that a process of integration might begin' (Meyer et al., 2010, p. xiii), 'there can be no ultimate full return to the pre-liminal state' (Meyer & Land, 2005, p. 376). Rational reflection with an emphasis on affective processes is seen as the main pedagogical strategy through which this transformation is achieved.

Research on threshold concepts has generated interesting insights into the nature of knowledge in different specialities. The work moves beyond the seemingly narrow notion of a 'concept' to address broader questions of knowing, knowledge practices, ways of seeing, emotions and experiences. It turns out that university teachers *within* each discipline show some consensus around the threshold concepts in their own discipline. However, what those threshold concepts are, why they are threshold and troublesome and what kind of curriculum change is needed to teach them more successfully vary *across* disciplines. For example, Carmichael (2012) comments that in engineering this has been mainly about identifying specific troublesome or integrative concepts that are taught in fragmented ways and redesigning around them a more effective curriculum. In social anthropology, this has been related to the development of the notion of 'reflexivity', the categories of culture and gender, the ability to reflect, not so much about practices, but more about spaces in which problematic issues could be made visible and thought through. In theology, the focus has been on challenges associated with 'reading biblical texts as literature' and seeing things differently. In English literature, it has been related the notion of 'ethical reading'.

6.4.1 Issues with Threshold Concepts from a Grounded Perspective

In our view, there are two important challenges in understanding research on threshold concepts.

First, as Perkins (2006) argues, what is troublesome partly depends on other factors – for example, students' approaches to learning have a powerful influence, as some students will simply try to resolve 'troublesome' problems by relying on memory and routine procedures, rather than trying to achieve a deep 'insider' feel for the ideas. Furthermore, students may have challenges achieving deep understanding because of certain inherent features of the knowledge. Perkins identifies five types of *troublesome knowledge* that inhibit this deeper learning:

Ritual knowledge – has a routine and meaningless feel and character. It forms a part of social or individual rituals. Dates and names and other simple facts can also have this character.

Inert knowledge – knowledge that students know, but do not use actively, does not connect to the world around them and does not transfer to real problems and other contexts.

Conceptually difficult knowledge – including counter-intuitive scientific knowledge, such as Newton's laws. Students learn this kind of knowledge in a rote, ritualised way and apply it to quantitative questions in school; but they use their intuitive beliefs to tackle qualitative problems and problems encountered outside the classroom.

Foreign or alien knowledge – knowledge that conflicts with one's own understanding, like seeing historical events from a present-day perspective, understanding the different value systems of other cultures and ethnic groups from within one's own value system and recognising that many situations 'allow multiple serious, sincere, well-elaborated perspectives that deserve understanding' (Perkins, 2006, p. 39).

Tacit knowledge – knowledge about which people are only peripherally aware or are entirely unconscious (as when using language, or conducting inquiry, in a domain without being conscious of what they are doing). While tacit knowledge can be highly efficient, Perkins notes

> . . . learners' tacit presumptions can miss the target by miles, and teachers' more seasoned tacit presumptions can operate like conceptual summaries that learners never manage to detect or track. (op cit., 40)

However, there is a sharp discontinuity between the nature of troublesome knowledge and the classical mode-based model of transformation adopted in the 'troublesome concept' pedagogies and research that we outlined above.

What is common across the five kinds of troublesome knowledge listed above is that they are all linked to what could be called 'grounded knowledge' – the kind of understandings that link what we know and how we act in the real world (see Sects. 6.2 above and 6.5 below). In contrast, the language describing (the learning of) threshold concepts and troublesome knowledge evokes ideas such as 'irreversibility', 'impossibility of progression' and the necessity of radical 'all or nothing' transformation in the students' minds. This assumption about students' *radically flawed* mental models or beliefs locks students' understanding up in their rational minds and invites teachers to draw upon the pedagogies of negative rationalism which discard students' intuitive knowledge: knowledge which is grounded in their experiences (see Sect. 6.3, above).

Disconnecting the embedded and embodied nature of troublesome knowledge and seeing a threshold concept as a deep-rooted 'flaw' in a student's intuitive mental model – one which needs to be eradicated and replaced – creates an unproductive opposition between knowing as intuitive situated action and articulated formal conceptual knowledge.

The key implication is that this view, by attributing students' learning difficulties to their minds (and mental models), significantly underestimates the extent to which troublesome knowledge and threshold concepts are *experiential* – that is, concepts grounded in situated experiences and students' mental resources.

The second issue we observe arises from the fact that concepts serve different purposes in human sense-making, problem-solving and inquiry (diSessa & Sherin, 1998; Keil & Silberstein, 1998). Indeed, Perkins (2006) lists several such functions:

Categorisers – most fundamentally, humans use concepts as conceptual categories for making sense of the world around them. 'They [concepts] carve up the world we already see and often posit the unseen or even the unseeable' (p. 41).

Frameworks and epistemic games – clusters of concepts set the stage for a more elaborate function. These clusters of concepts form activity systems or conceptual games. For example, the 'Freudean self' provides a broad scaffold for interpretation, diagnosis and treatment; styles of art (impressionism, surrealism, etc.) provide means for marking trends and tracing influences.

Many of the troubles relating to concepts do not arise from their *categorical* function (as described above), but from the larger *conceptual games* around them – ‘the activity systems that animate concepts’ (Perkins, 2006, p. 41). As Perkins says, it is easy to ‘get’ the concept of ‘bias’ in historical sources, but harder to use it in actually analysing historical sources or in making other decisions about historical evidence. Many troubles come from their tacit nature – teachers play the epistemic games of their disciplines fluently and automatically, so trouble arises from the fact that the games and their rules receive little explicit attention. However, threshold concept pedagogies that focus mainly on reflective discourse pay little attention to the material embodied nature of epistemic practices and epistemic games in many professions. We must not forget that experts become skilful at epistemic work not just by reflecting but by actually using the epistemic tools of the domain and playing the epistemic games of the profession (we develop these ideas further in Chap. 9 and after). We now return to the nature of the human cognitive system that underpins conceptual understanding.

6.5 Grounding Conceptual Knowledge in Experience: Situated Concepts

While conceptual knowledge accounts for only a part of what people know, it plays a fundamental role in *organising* human cognition. Just as human existence in a material world involves static, dynamic and emerging things (a chair, hammer, air, wind, rain, law, thought), similarly, human cognition is impossible without concepts for naming those things. That said, how the human conceptual system works and how it relates to experiences in the material and physical world are still not well understood.

A useful way of thinking about some of the fundamental differences between views of human knowledge and of how knowledge relates to the world can be found in Lawrence Barsalou’s (2009) contrast between the *semantic* and *situated* views of conceptual systems; these dominate contemporary cognitive research.

The *semantic* view sees human memory as composed of two independent parts: (a) episodic memory, which contains records of experiential episodes with temporal and spatial relationships and other experiential details, and (b) semantic memory, which contains conceptual knowledge from which episodic details[4] have been filtered out. On this view, semantic memory is held to be relatively autonomous from episodic memory and operates independently from perception, action, emotions and other senses. Semantic knowledge is held to be represented in an internal symbolic (amodal) form that is different from (stripped of) the modalities of the

[4] Such as the circumstances in which the concepts were first encountered (e.g. the name and appearance of the physics teacher who first taught you Newton’s laws).

external world, such as vision, action or affect. Semantic memory representations are relatively stable and generally shared among people.

Barsalou, drawing on recent neuroscientific evidence, rejects this semantic view and argues that human conceptual knowledge is *inherently situated*. He argues that human conceptual knowledge remains tightly linked ('packaged') with information from the background situations in which it was encountered. He specifically identifies four types of situated information that is stored together with conceptual categories: (a) selected properties of the conceptual category relevant to the current situation, (b) information about the background settings, (c) possible actions that could be taken and (d) perceptions of internal states that one might have experienced during previous encounters with the conceptual phenomena, such as affects, motivations, cognitive states and cognitive operations. Barsalou (2009) argues that the conceptual system is not abstract and detached, rather it

> . . . constructs situated conceptualizations dynamically, tailoring them to the current needs of situated action . . . [constructing experiences of] being there with category members. (Barsalou, 2009, p. 251)

These 'packages' prepare humans for situated action and can be used to guide a goal-directed activity that unfolds in a new situation. The concept is not separated from the conceptualiser. The actions and introspective states, which are *re-enacted* during the process of simulating a category, create for the conceptualiser the experience of being in the situation. In short, conceptual thinking does not involve processing of abstract, amodal symbols; rather, it is a creative, dynamic re-enactment of cognitive states that are distributed across modality-specific systems (e.g. audition, movement, emotion).

Barsalou argues that the conceptual system supports a range of 'online' and 'offline' cognitive activities. In online processing – that is, when people are engaged in a purpose-oriented physical activity – the conceptual system (a) supports perceptual processing via figure-ground segregation, anticipation and filling in gaps; (b) predicts the entities and events likely to be present; (c) produces mapping into categories of those entities and events; and (d) produces inferences, based on categorisations, about what they are likely to do next, how to interact with them and other actions.

In offline processing – that is, when people think about entities that are not present – the conceptual system supports memory, as it helps reconstruct things that are remembered; it supports language by supporting interpretation and generation of inferences; it supports thought as it represents entities, events and states that constitute the content of reasoning, decision-making and other similar cognitive tasks. Situated concepts play important roles in optimising cognitive processing and prediction as simulated representations are selective, episodic and simplify many tasks. Barsalou also notes that similar conceptualisation processes underpin concepts that have quite diverse origins, including concepts developed through experience and concepts established by means of reasoning. Overall, this conceptual system is highly flexible. Previously remembered concepts may be merged together during re-enactment in a variety of ways. Further, deliberative efforts to combine components and simulations of several conceptual instances can produce novel conceptual categories – that is, new knowledge.

Such a conceptual system is not a traditional representational device, rather it is a performative device for creating situated conceptualisations.

> Conceptual knowledge is not a global description of a category that functions as a detached database about its instances. Instead, conceptual knowledge is the ability to construct situated conceptualizations of the category that serve agents in particular situations. (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003, p. 89)

In research over the last three decades (or more), an unhelpful Cartesian divide has persisted, between understanding and doing, mind and body, representation and interaction, cognitive and sociocultural, symbolic and situated and material and conceptual. Recent research on grounded cognition is providing more and better evidence about the productive roles of experiences that are outside the 'symbolic mind' – including attitudes, social perception and emotion – in generating conceptual understanding and supporting ways of knowing that are beyond the situated, including conceptual knowledge, mindfulness and everyday creativity (Barsalou, 1999, 2008, 2009; Barsalou & Prinz, 1997).

What Barsalou has been saying persuasively, over the last 20 years, now seems obvious: human understanding, backgrounds, related actions and internal states are closely related aspects of the same conceptual system. In short, perception, understanding, doing and being are not separated by walls in the human mind or brain, but are separated by the situations in which people experience these different ways of knowing. Thinking and other conceptual mechanisms of the mind are inherently grounded in the situated experiences of the environment, the body and the act of perceiving and acting.

This view of human cognition as 'grounded' in situated experiences provokes the question of whether these Cartesian divides have not been merely 'threshold concepts' for educators and educational researchers, who have sought to replace students' situated experiences with abstract concepts and have missed the continuity between conceptual knowledge and practical experience. Conceptual knowledge for knowledgeable action can and should be grounded in local contexts and in 'hands-on' experiences. (Nurses do not just look after the abstract category of 'hypertension'; rather, they centre their work on, and think about, the patient with hypertension – a specific instance, if you like, of the situated concept.)

6.6 Conceptual Understanding and Actionable Knowledge

In order to help students develop actionable knowledge for professional work, we need to have a feasible account of a mechanism for how actionable knowledge operates and develops. What kinds of mental entities underpin the professional understanding that enables action? How are these entities entangled in action? How do they change? In short, what kinds of mental resources could provide students with a sufficient start for (a) fluent decisions and actions in more familiar, ordinary situations and (b) further changes and reconfigurations of knowledge and skills to cope with new situations and to innovate – that is, to help them be 'workplace ready' *and* prepared for lifelong learning and innovation in a changing work environment?

Few pedagogical models of professional education and expertise have been sufficiently careful in distinguishing between the human conceptual system, through which the mind brings forth meaning, and the normative conceptual system employed in expert discourse. Further, symbolic (information processing) accounts of the human conceptual system have informed, in a deep sense, much of the pedagogical thinking that has emerged in 'all or nothing' and 'something or nothing' accounts of conceptual change (e.g. Meyer & Land, 2005). Pedagogies for confronting troublesome knowledge and dislodging habituated skills – while they may have shifted some distance away from a purely rationalistic logic – have nevertheless maintained their deeply negative 'deficiency' view towards the intuitions students bring to higher education. However, such pedagogical ideas have not proved strong enough to account for the fluency and flexibility that is observed, needed and valued in the successful performance of expert (and novice) professionals in dynamically changing workplace settings. It is not a surprise that a common response to this conundrum has been to run away from conceptual knowledge and skills and look for answers solely in terms of students' dispositions and other 'human qualities' (Barnett, 2004).

In contrast, our account – broadly drawing on Greeno's (2012) notions of 'formal knowledge' and 'functional knowledge' – makes an explicit distinction between *normative* knowledge (and concepts that have formal definitions and formal uses in expert discourse) and *enacted* knowledge (and experiential concepts employed in human sense-making and skill). It builds on the fundamental assumption that actionable knowledge is grounded, dynamic knowledge. From this perspective, professional understanding and learning are a form of knowledge and knowing that draws upon, and constitutively entangles, (a) some core features of the common-sense understandings that underpin everyday sense-making and action and (b) the normative forms of knowledge embedded in the formal expert discourse of a professional community. Following this line of argument, we suggest that actionable knowledge is underpinned by a conceptual system of what we call *actionable concepts* – including *actionable conceptual and epistemic mental resources*. These actionable concepts project, blend and entangle the normative conceptual system of the professional field with the common-sense experiential concepts and ways of thinking developed through experiences and engagement with the world (they are absolutely not reducible to replacing the latter with the former).

'Action' and 'knowledge' play equally fundamental roles in the human conceptual system – so professional understanding and learning should constitutively entangle these two aspects of intelligent behaviour.

On the one hand, actionable knowledge is materially and socially *thick* knowledge – grounded in experiences, perception, introspection, affect and action. Such knowledge comes from (less articulated) empirical engagement with authentic situations. Thus, the human conceptual system that underpins sense-making and skill is, at least in part, intuitive, opportunistic and heuristic, closely coupled with the affordances of the situation, previous experiences, perception and action (Barsalou, 1999, 2009). It is therefore *not* predominantly abstract and rational.

On the other hand, professional understanding draws on substantial amounts of quite decontextualised knowledge, learnt via discourse, but extracted from the natural contexts in which it has been created and will be enacted in the future. To be clear, we are not underestimating the value of formal conceptual knowledge. On the contrary, we believe there is sufficient evidence, from such knowledge-intensive professions as medicine, engineering and the law, to be in no doubt that formal conceptual knowledge and formal reasoning strategies provide an important resource for expert decision-making in many complex, non-routine situations (e.g. Patel, Arocha, & Zhang, 2005). Indeed, the conceptual resources and ways in which experts draw upon this knowledge in solving problems in non-routine situations offer a good basis for thinking about what kinds of 'actionable conceptual system' (including strategies) may prove to be productive for students who are entering the professional field. (For novices, many situations are new and complex. Thus productive expert ways of thinking in unfamiliar circumstances have a reasonably good chance of overlapping with ways of thinking that might be helpful to novices initially and throughout their career.)

In short, a well-formed conceptual system for actionable knowledge should (a) draw upon and integrate different kinds of mental resources, from formal concepts of the domain to situated conceptualisations, construed in the here and now, through direct engagement with an encountered challenge and (b) be flexible, and well enough tuned, to attend to a variety of contexts and deal with situational variations. That is, conceptual thought for knowledgeable action cannot operate in a closed, decontextualised, conceptual space which does not have a solid connection to details of the situation. (We elaborate on this in Chaps. 17 and 18.)

6.7 Transfer

The two broad views on the nature of conceptual understanding and conceptual change permeating our analyses above can also be seen in the literature on transfer (diSessa & Wagner, 2005; Lobato, 2012; Wagner, 2006, 2010).

Those views which see conceptual learning and change as a sudden shift from one (incorrect) to another (correct) abstract and coherent conceptual system explain students' difficulties with transfer as a failure to assimilate a new situation into an existing abstract conceptual system. According to this view, the abstract conceptual structure should already be in place. Transfer can start once conceptual change is finished.

The knowledge-in-pieces perspective, in contrast, locates the issue of transfer rather differently (Wagner, 2006, 2010). From this perspective, the ability to use a concept in one context does not necessarily imply an ability to use the concept across all contexts. Learning a concept requires a coordination of a range of elements associated with a specific context,

To understand transfer and its problems more clearly, it is useful to look more deeply at the nature of the conceptual structures that underpin transfer. We outline three views on these structures: 'models', 'modules' and 'modalities'. As a part of the latter view, we introduce an actor-oriented view of transfer, which is particularly helpful in considering transfer in professional education and work (Lobato, 2012; Nemirovsky, 2011).

6.7.1 The Model Perspective

The model perspective is associated with mainstream cognitive research. From this perspective, transfer can be defined in terms of someone having a formal abstract concept and being able to apply it to diverse contexts by identifying abstract connections between new tasks and what is already familiar.[5] These connections can be made using one or more of a variety of mechanisms, ranging from a simple direct mapping between the abstract principles and the situation to a cognitively much more costly application of interpretative rules for translating previously learnt declarative knowledge into a set of procedures relevant for a task in a given situation (see, e.g. Nokes, 2009). A representative formulation of this model view can be found in Fuchs et al. (2003). They describe transfer as a two-stage process of abstraction and metacognition:

> To *abstract* a principle is to identify a generic quality or pattern across instances of the principle. In formulating an abstraction, a individual *deletes details across exemplars*, which are irrelevant to the abstract category (e.g., ignoring the fact that an airplane is metal, and that a bird has feathers, to formulate the abstraction of "flying things"). These abstractions are represented in symbolic form and avoid contextual specificity, so they can be applied to other instances or across situations. Because abstractions, or schemas, subsume related cases, they promote transfer. With *metacognition*, an individual *withholds* an initial response and, instead, deliberately examines the task at hand and generates alternative solutions by considering ways in which the novel task shares connections with familiar tasks. (Fuchs et al., 2003, p. 294, emphasises added)

Lobato (2012) summarises the common features of this perspective on transfer:

> First, the formation of sufficiently abstract representations is a necessary condition for transfer (so that properties and relations can be recognized in both initial and transfer situations), where abstraction is conceived as a process of decontextualization ... Second, explanations for the occurrence of transfer are based on the psychological invariance of symbolic mental representations ... Finally, transfer occurs if the representations that people construct of initial learning and transfer situations are identical, overlap, or can be related via mapping. (Lobato, 2012, p. 233)

[5] Threshold concepts (Sect. 6.4) can also be thought of in this way.

As this perspective builds on the classic symbol-processing architecture, human perception and human conception are seen as two independent mechanisms of the human mind: one ‘perceives’ and the other does the ‘thinking’. The transfer is the job of the former rather than the latter mechanism.

6.7.2 The Module Perspective

The second way is to see transfer as ‘modular’. Rather than having one structure that accounts for a certain concept, this perspective posits a set of context-sensitive mental resources that allow one to see situations as similar and transfer knowledge from one context to another. Redish (2004) in physics and Wagner (2006, 2010) in mathematics illustrate this kind of transfer.

The main principle that underpins this view is that transfer does not happen via constructing and having ‘expert-like’ abstractions. Instead it involves constructing middle-ground phenomenological abstractions called ‘coordination classes’ which operate in specific contexts and then projecting them to a common ‘expert-like’ structure. These coordination classes are sets of ‘systematically connected ways for seeing things in the world’ (diSessa & Sherin, 1998, p. 117). They are grounded in experiences and contexts, but by being projected to generic structures, work as appropriate substitutes for formal ways of thinking in particular contexts. From this perspective,

> Transfer is understood not as the all-or-nothing transportation of an abstract knowledge structure across situations, but as the incremental growth, systematization, and organization of knowledge resources that only gradually extend the span of situations in which a concept is perceived as applicable. (Wagner, 2006, p. 10)

This view of transfer shifts the focus of conceptual learning from the formation of abstract representations to developing capacities to ‘read out’ contextual details and firmly link conceptual understanding with a growing diversity of situated experiences of the phenomenon in the world. As Wagner (2006) explains,

> . . . transfer is the natural outgrowth of increased understanding, and understanding a principle is inseparable from developing appropriate readout strategies and coordination knowledge, as well as particular concept projections, that permit it to be useful in a variety of situations. The more complex and varied a particular knowledge frame grows, the more likely it is to be cued across many situations, and the more readily and flexibly it can be used to interpret any situation in which it is applied. (op. cit., pp. 64–65)

Attention to particularities of the context is the key to transfer in this ‘module-like’ organisation. It is not about formulating abstractions by deleting contextual details, but *specifically paying attention to them*, recognising similarities and differences between two contexts and projecting to a similar overarching concept. This perspective draws on the ‘knowledge-in pieces’ view of conceptual change and learning (diSessa 1988, 1993; and see Sect. 6.3.3). The initial context-specific abstractions may even be learnt without much formal teaching, but rather are gradually projected and integrated into a more coherent and coordinated conceptual machinery of complex conceptual thinking.

If we take this perspective on transfer seriously, the traditional view of transfer that is based on 'formal concepts' as assimilatory structures used by experts to 'see the world' is at odds with how transfer really happens.

> In this sense, the structure one perceives in a situation is actively constructed through an interaction of available contextual affordances and prior learning experiences, thereby denying a temporal sequence of *first* representing or structuring a situation and *then* applying prior knowledge. (Wagner, 2010, p. 448, original emphasis)

As Wagner (2010) argues – and others illustrate (Gupta et al., 2010) – even experts continue to use different non-formal, experientially constructed, conceptual projections for making sense of scientific phenomena. While abstract principles allow a scientific community to construct general theories and a shared understanding of various phenomena, these principles do not necessarily correspond to the cognitive mechanisms underpinning human reasoning and sense-making about these phenomenon.

> If different contexts cue different knowledge elements, and if different structural interpretations are more "natural" to different situations, there is no reason to expect that those varying forms of knowledge will be less useful or abandoned in the future. (Wagner, 2010, p. 475)

6.7.3 The Modality Perspective

The third way is to think about transfer of concepts in action from the situated conceptualisation perspective – a concept as modality coordination (Barsalou, 1999, 2009). In this case, the concept is not seen as situated in a one-dimensional context, as it is in the modular view. Rather, many cultural and action frames structure perception simultaneously, and a number of senses are involved: the concept and the context become multimodal.

> They [agents] perform sets of coordinated tasks that produce coherent behaviour. For example, organisms do not produce categorisation alone. Instead, they perform categorisation together with perception, inference, action, reward, and affect. (Barsalou et al., 2007, p. 83)

As Barsalou (1999, 2009) argues, such a system is grounded in perception and action. Multiple modalities of the phenomenon experienced in the world – via vision, touch, smell, audition, emotion and so on – are an integral part of knowledge representations and processes through which knowing becomes possible. For example, a pianist's ability to simulate action underlies their ability to recognise records of their own performances and synchronise with them (Keller, Knoblich, & Repp, 2007). Further, much of this cognition is closely coupled with specific background information in which the phenomenon was experienced. Barsalou (2009) illustrates this with the observation that when people encounter the word 'piano' in a sentence about moving pianos, they primarily activate information related to its modality of being 'heavy', whereas when they encounter the same word in a sentence about playing the piano, they think about a 'pleasant sound'. When asked to think about a scene that is not present, people usually infer background details. Further, this simulation extends to possible situated actions, emotions and other experiences.

Moreover, the concept is situated in the frame of a problem that is structured around the perception–action interface (following Barsalou). Thus, it is in the same conceptual neighbourhood as other concepts relevant to interpreting the situation. From this perspective, *transfer is not an application of a ready-made conceptual package but the process that emerges from blending different coordinated ways of structuring a situation* (a.k.a. frames) *and fusing different multimodal conceptual structures into one actionable concept* that guides perception of the situation and action.

This modality perspective closely resembles the view of Actor-Oriented Transfer (AOT), which is gaining some recognition in educational research (Lobato, 2012). This view of transfer similarly emphasises the highly interpretative nature of human conceptual thinking, particularly when people work with problems in complex, semantically rich domains. In such domains, problems are often open to multiple, usually idiosyncratic, ways of structuring various aspects of the situation and naturally lean to diverse interpretations and solutions. Perception and structuring of the encountered situation are seen as highly interactive and sensitive to the context process that heavily leans on personal goals, perceived affordances and diverse prior experiences:

> *Structuring* is contrasted with the view of extracting a *structure* from a situation, where . . . a closer correspondence between the external world and mental structures is often assumed. Relatedly, AOT is rooted in the notion of reflective abstraction, . . . which is a constructive rather than inductive formulation of abstraction. It focuses on the abstraction of regularities in records of experience in relationship to one's goals and expectations, rather than on regularities inherent in a situation or the encoding of common properties across instances. (Lobato, 2012, p. 243, original emphasis)

In contrast to the traditional model view that focusses on the transfer of well-defined strategies, or other knowledge, from one situation to another, the AOT perspective takes a holistic view and focusses on how students' prior experiences, independently from their origins, shape students' activity – constructing situated conceptualisations rather than transferring predetermined strategies. Transfer is about coordinating individual cognitive processes and social interaction in material, culturally shaped environments via 'noticing'. As Lobato emphasises:

> . . . transfer is a distributed phenomenon across individual cognition, social interactions, material resources, and normed practices. <. . .> By noticing, we do not mean simply "paying attention" but rather the selecting and processing of particular properties, features, or conceptual objects, when multiple sources of information compete for one's attention. (op. cit., pp. 241–242)

In professional work, this learning to notice, as Goodwin (1994) remarks, is not a simple psychological process but a complex, socially situated activity.

Table 6.2 Main features of the three perspectives on transfer

	Model view	Module view	Modality view
Mental constructs for transfer	Mental schemas, beliefs	Coordination classes and projections	Mechanisms for constructing multimodal situated conceptualisations
Main aspects that contribute to transfer	Mind	Mind and context	Mind, social interactions, language, cultural artefacts, normed practices
Nature of problems	Generic tasks with a rule-oriented, procedural focus	Common context-specific problems	Semantically rich problem domains
Point of view	An observer's view	Link between observer's and actor's views	An actor's view
What transfers	Well-defined strategies, solution methods, action schemas	Bottom-up constructed conceptualisations and solution methods	Construction of conceptualisations
Main difficulty of transfer	*Mapping* that relates features of representations constructed during initial learning and new transfer situations	*Projection* of various experiential concepts to the same abstract conceptual principle or category	*Noticing* – selecting, interpreting and working with particular features when multiple sources of information compete for attention

Table 6.2 summarises the main features of the model, module and modality views on transfer.

6.8 Dynamic Expertise, Transfer and Innovation

6.8.1 Dynamic Expertise as Coordination

The link between perception and conception tends to be very intimate and complex in professional knowledgeable action. Rules and logic do not replace fine-tuned perception in complex, situated, problem-solving. Understanding emerges from the coordination of the two.

This is nicely illustrated by Gupta et al. (2010) who show that expert physicists do not reason using one correct ontology that underpins deep properties of physical, non-material phenomena (such as light). Rather, they switch between ontologically correct ways of reasoning about the emergent processes and the matter-based reasoning that underpins 'surface' or 'naïve' intuitions. They argue,

> Our sense organs and our brain's tools for interpreting the data from these sense organs are an evolutionary 'satisfice'. (Gupta et al., 2010, p. 305)

Science tries to understand the world at a deeper analytical level. Scientific theories supplement our limited direct experiences and ontological categories. But the way they do this is by mixing and blending the observable and non-observable, context dependent and abstract, rather than by replacing one ontological category with another.

At the core of this way of reasoning, is what Gupta et al. call a 'dynamic perspective'

> [The] dynamic perspective emphasises the development of skills to evaluate the productiveness of multiple descriptions. <. . .> Developing expertise means that students become aware of the productiveness and limitations of the descriptions they use and the resources that they have at hand. (op. cit., p. 316)

Such mixing, switching and blending become evident in experts' and students' thinking. For example, teachers do not work with abstract theories or strategies that are based on a distinct ontology that underpins the concept 'constructivism'. They work in real classroom with real children – an ontology that underpins material and social arrangements. Similarly, a pharmacist does not dispense abstract chemical properties to a patient; she dispenses 'pills' and 'boxes' as medications. In essence, the conceptual is blended with the material, and concepts have a meaning in professional practice if they can travel across 'surface' material and 'deep' conceptual/ontological categories of professional knowledge (we illustrate this in Chaps. 17 and 18).

This contrasts with much of the threshold concepts' literature, which focusses on getting expert discourse 'straight' as the main objective of learning and which aims to suppress discourse and intuitions that do not fit this expert shape.

6.8.2 Dynamic Transfer and Innovation

Schwartz, Varma and Martin (2008) make an important observation noting that knowledge 'as repetition' and knowledge 'as use of prior learning' are not the same.

> Asking how people become more efficient via repetition is different from asking how people build on prior knowledge. (Schwartz et al., 2008, p. 482)

They go on to point out that education aims to equip students with knowledge that is 'ready for application' and also to prepare students to act as innovators in the future. They relate this to a discussion of transfer. They draw an explicit distinction between 'transfer for innovation' and change and 'transfer for repetition' – 'dynamic transfer' and 'similarity transfer' (see Table 6.3). *Similarity transfer* primarily concerns situations when knowledge learnt in one situation is deployed in another; *dynamic transfer* concerns situations when prior learning is used to create new knowledge. Dynamic transfer involves coordination of different sources of behaviour – mental, social and physical – and different types of knowledge, including different states of understanding and abilities.

Table 6.3 Comparison of similarity transfer and dynamic transfer

	Similarity transfer	Dynamic transfer
Purpose	Transfer for repetition	Transfer for change and innovation
Mechanism	'This is like that' – transfer by analogy, mapping	'This goes with that' – coordinating and making relationships among mental, social and physical systems
Concept	Well-formed before transfer	Formed during transfer
Formation	Concepts are formed in one situation, but applied in another, in new ways	Coordinate separate components to create a new concept first
Conceptual learning	'All or nothing'	An iterative process of building new relationships and new insights

After Schwartz et al. (2008)

How do people learn to be innovative? Schwartz et al. propose that innovative behaviour and thinking involve both similarity transfer and dynamic transfer. In their view, innovation is primarily about the mindset and about learning to see important environmental structures and create external representational resources that enable dynamic transfer.

> [The] ability to transfer and innovate grows from experiences where people gain insight into important environmental structures and their possibilities for interaction. (Schwartz et al., 2008, p. 502)

Keil and Silberstein (1998) make similar point, and link this kind of mindset and skill to the productive cognition of 'expert learners'.

> Expertise itself might require many years to develop if it is defined as requiring both ample experience and the ability to handle novel situations; but expert-like behavior can be exhibited by both novices and children. In such cases the learner is constantly trying to construct new and better knowledge structures for handling a problem, rather than merely trying to shoehorn the problem into older conceptions. <…> The expert learners, on the other hand, are able to create a new category to fit the novel style and try to incorporate it on its own terms. They are willing to expand the limits of their previous knowledge and adapt the knowledge to fit the data. (Keil & Silberstein, 1998, p. 636)

This kind of expertise draws on special kinds of mental constructs – epistemic rather than conceptual resources. We turn to these in the next chapter.

References

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Anderson, M. L. (2003). Embodied cognition: A field guide. *Artificial Intelligence, 149*(1), 91–130. doi:10.1016/s0004-3702(03)00054-7.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher, 25*(4), 5–11. doi:10.3102/0013189x025004005.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (Vol. 2, pp. 89–195). New York, NY: Academic Press.

Barnett, R. (2004). Learning for an unknown future. *Higher Education Research & Development, 23*(3), 247–260.
Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.
Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*, 577–609.
Barsalou, L. W. (2003). Situated simulation in the human conceptual system. *Language and Cognitive Processes, 18*(5–6), 513–562. doi:10.1080/01690960344000026.
Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645. doi:10.1146/annurev.psych.59.103006.093639.
Barsalou, L. W. (2009). Situating concepts. In P. Robbins & M. Aydede (Eds.), *The Cambridge handbook of situated cognition* (pp. 236–263). Cambridge, MA: Cambridge University Press.
Barsalou, L. W. (2010). Grounded cognition: Past, present, and future. *Topics in Cognitive Science, 2*(4), 716–724. doi:10.1111/j.1756-8765.2010.01115.x.
Barsalou, L. W., Breazeal, C., & Smith, L. (2007). Cognition as coordinated non-cognition. *Cognitive Processing, 8*(2), 79–91. doi:10.1007/s10339-007-0163-1.
Barsalou, L. W., Kyle Simmons, W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences, 7*(2), 84–91. doi:10.1016/s1364-6613(02)00029-3.
Barsalou, L. W., & Prinz, J. J. (1997). Mundane creativity in perceptual symbol systems. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 267–307). Washington, DC: American Psychological Association.
Bereiter, C. (1991). Implications of connectionism for thinking about rules. *Educational Researcher, 20*(3), 10–16.
Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ: Lawrence Erlbaum Associates.
Billett, S. (1996). Situated learning: Bridging sociocultural and cognitive theorising. *Learning and Instruction, 6*(3), 263–280.
Boivin, N. (2008). *Material cultures, material minds: The impact of things on human thought, society and evolution*. Cambridge, UK: Cambridge University Press.
Boud, D., & Feletti, G. (Eds.). (1997). *The challenge of problem based learning* (2nd ed.). London, UK: Kogan Page.
Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
Brookfield, S. (1986). *Understanding and facilitating adult learning*. Milton Keynes, UK: Open University Press.
Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence, 47*, 139–159.
Brooks, R. A., & Stein, L. A. (1994). Building brains for bodies. *Autonomous Robots, 1*, 7–25.
Carmichael, P. (2012). Tribes, territories and threshold concepts: Educational materialisms at work in higher education. *Educational Philosophy and Theory, 44*(sup1), 31–42. doi:10.1111/j.1469-5812.2010.00743.x.
Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14*(2), 161–199.
Chi, M. T. H., De Leeuw, N., Chiu, M.-H., & Lavancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*(3), 439–477. doi: http://dx.doi.org/10.1016/0364-0213(94)90016-7
Chi, M. T. H., & Ohlsson, S. (2005). Complex declarative learning. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 371–400). Cambridge, MA: Cambridge University Press.
Chi, M. T. H., & Roscoe, R. (2002). The processes and challenges of conceptual change. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 3–27). Dordrecht, The Netherlands: Kluwer.

Clark, A. (1999). Embodied, situated and distributed cognition. In W. Bechtel & G. Graham (Eds.), *A companion to cognitive science* (pp. 506–517). Oxford, UK: Basil Blackwell.
Clark, R. C. (2008). *Building expertise: Cognitive methods for training and performance improvement* (3rd ed.). San Francisco, CA: John Wiley & Sons.
Clark, A. (2011). *Supersizing the mind: Embodiment, action and cognitive extension*. Oxford, UK: Oxford University Press.
Clark, A. (2012). Embodied, embedded, and extended cognition. In K. Frankish & W. M. Ramsey (Eds.), *The Cambridge handbook of cognitive science* (pp. 275–291). New York, NY: Cambridge University Press.
Cole, M. (1996). *Cultural psychology*. Cambridge, MA: Harvard University Press.
Cole, M., Engeström, Y., & Vasquez, O. A. (Eds.). (1997). *Mind, culture, and activity: Seminal papers from the laboratory of comparative human cognition*. Cambridge, UK: Cambridge University Press.
Colley, A., & Beech, J. (Eds.). (1989). *Acquisition and performance of cognitive skills*. Chichester, UK: John Wiley & Sons.
Dall'Alba, G. (2009). *Learning to be professionals*. Dordrecht, The Netherlands: Springer.
Dall'Alba, G., & Barnacle, R. (2007). An ontological turn for higher education. *Studies in Higher Education, 32*(6), 679–691. doi:10.1080/03075070701685130.
Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York, NY: G.P. Putnam.
Damasio, A. R. (2012). *Self comes to mind: Constructing the conscious brain*. New York, NY: Vintage Books.
de Jong, T., van Gog, T., Jenks, K., Manlove, S., van Hell, J., Jolles, J., . . . Boschloo, A. (2009). *Explorations in learning and the brain: On the potential of cognitive neuroscience for educational science*. New York, NY: Springer
diSessa, A. A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the computer age* (pp. 49–70). Hillsdale, NJ: Lawrence Erlbaum Associates.
diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*(2/3), 105–225.
diSessa, A. A. (2000). Does the mind know the difference between the physical and social worlds? In L. Nucci, G. B. Saxe, & E. Turiel (Eds.), *Culture, thought, and development* (pp. 141–166). Mahwah, NJ: Lawrence Erlbaum Associates.
diSessa, A. A. (2006). A history of conceptual change research: Threads and fault lines. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 265–293). Cambridge, UK: Cambridge University Press.
diSessa, A. A. (2008). A bird's-eye view of the "pieces" vs. "coherence" controversy (from the "pieces" side of the fence). In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 35–60). New York, NY: Routledge.
diSessa, A. A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155–1191.
diSessa, A. A., & Wagner, J. F. (2005). What coordination has to say about transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 121–154). Greenwich, CT: Information Age.
Dreyfus, H. L. (1992). *What computers still can't do: A critique of artificial reason*. Cambridge, MA: MIT Press.
Dreyfus, H. L. (2014). *Skilful coping: Essays on the phenomenology of everyday perception and action*. New York, NY: Oxford University Press.
Engeström, Y. (2008). *From teams to knots: Activity-theoretical studies of collaboration and learning at work*. Cambridge, NY: Cambridge University Press.
Fuchs, L. S., Fuchs, D., Prentice, K., Burch, M., Hamlett, C. L., Owen, R., . . . Jancek, D. (2003). Explicitly teaching for transfer: Effects on third-grade students' mathematical problem solving. *Journal of Educational Psychology, 95*(2), 293–305.

Geake, J. (2009). *The brain at school: Educational neuroscience in the classroom*. Buckingham, UK: Open University Press.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford, UK: Oxford University Press.

Goleman, D. (2006). *Emotional intelligence*. New York, NY: Bantam Books.

Goodson-Espy, T. (2005). *Why reflective abstraction remains relevant in mathematics education research*. Paper presented at the annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education.

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606–633.

Greeno, J. G. (2012). Concepts in activities and discourses. *Mind, Culture, and Activity, 19*(3), 310–313. doi:10.1080/10749039.2012.691934.

Gupta, A., Hammer, D., & Redish, E. F. (2010). The case for dynamic models of learners' ontologies in physics. *Journal of the Learning Sciences, 19*(3), 285–321.

Hallden, O., Scheja, M., & Haglund, L. (2008). The contextuality of knowledge: An intentional approach to meaning making and conceptual change. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 509–532). New York, NY: Routledge.

Holland, D., & Quinn, N. (Eds.). (1987). *Cultural models in language and thought*. Cambridge, UK: Cambridge University Press.

Hoyles, C., Noss, R., & Pozzi, S. (2001). Proportional reasoning in nursing practice. *Journal for Research in Mathematics Education, 32*(1), 4–27.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Hutchins, E. (2010). Cognitive ecology. *Topics in Cognitive Science, 2*(4), 705–715. doi:10.1111/j.1756-8765.2010.01089.x.

Ingold, T. (2011). *Being alive: Essays on movement, knowledge and description*. Abingdon, UK: Routledge.

Jarvis, P. (2012). *Adult learning in the social context* (Vol. 78). New York, NY: Routledge.

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments*. New York, NY: Routledge.

Kapur, M. (2008). Productive failure. *Cognition and Instruction, 26*(3), 379–424. doi:10.1080/07370000802212669.

Kaufman, D. R., Keselman, A., & Patel, V. L. (2008). Changing conceptions in medicine and health. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 295–327). New York, NY: Routledge.

Keil, F. C., & Silberstein, C. S. (1998). Schooling and the acquisition of theoretical knowledge. In D. R. Olson & N. Torrance (Eds.), *The handbook of education and human development* (pp. 621–645). Malden, MA: Blackwell.

Keller, P. E., Knoblich, G., & Repp, B. H. (2007). Pianists duet better when they play with themselves: On the possible role of action simulation in synchronization. *Consciousness and Cognition, 16*(1), 102–111. doi:10.1016/j.concog.2005.12.004.

Keselman, A., Kaufman, D. R., & Patel, V. L. (2004). "You can exercise your way out of HIV" and other stories: The role of biological knowledge in adolescents' evaluation of myths. *Science Education, 88*(4), 548–573. doi:10.1002/sce.10135.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86. doi:10.1207/s15326985ep4102_1.

Kirsh, D. (2009). Problem solving and situated cognition. In P. Robbins & M. Aydede (Eds.), *The Cambridge handbook of situated cognition* (pp. 264–306). Cambridge, MA: Cambridge University Press.

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge, MA: Harvard University Press.

Knowland, V. P., & Thomas, M. C. (2014). Educating the adult brain: How the neuroscience of learning can inform educational policy. *International Review of Education, 60*(1), 99–122.
Kuhn, D. (2007). Is direct instruction an answer to the right question? *Educational Psychologist, 42*(2), 109–113.
Land, R., & Meyer, J. H. F. (2010). Threshold concepts and troublesome knowledge (5): Dynamics of assessment. In J. H. F. Meyer, R. Land, & C. Baillie (Eds.), *Threshold concepts and transformational learning* (pp. 61–80). Rotterdam, The Netherlands: Sense.
Land, R., Meyer, J. H. F., & Baillie, C. (2010). Editors' preface: Threshold concepts and transformational learning. In J. H. F. Meyer, R. Land, & C. Baillie (Eds.), *Threshold concepts and transformational learning* (pp. IX–XLII). Rotterdam, The Netherlands: Sense.
Land, R., Meyer, J., & Smith, J. B. (Eds.). (2008). *Threshold concepts within the disciplines*. Rotterdam, The Netherlands: Sense.
Lave, J. (1988). *Cognition in practice*. Cambridge, MA: Cambridge University Press.
Lave, J. (2012). Changing practice. *Mind, Culture, and Activity, 19*(2), 156–171. doi:10.1080/10749039.2012.666317.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press.
Lobato, J. (2012). The actor-oriented transfer perspective and its contributions to educational research and practice. *Educational Psychologist, 47*(3), 232–247. doi:10.1080/00461520.2012.693353.
Malafouris, L. (2013). *How things shape the mind: A theory of material engagement*. Cambridge, MA: MIT Press.
Marton, F., & Pang, M. F. (2008). The idea of phenomenography and the pedagogy of conceptual change. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 533–559). New York, NY: Routledge.
McGann, M., De Jaegher, H., & Di Paolo, E. (2013). Enaction and psychology. *Review of General Psychology, 17*(2), 203–209.
Meyer, J. H. F., & Land, R. (2005). Threshold concepts and troublesome knowledge (2): Epistemological considerations and a conceptual framework for teaching and learning. *Higher Education, 49*(3), 373–388.
Meyer, J. H. F., & Land, R. (Eds.). (2006). *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge*. London, UK: Routledge.
Meyer, J. H. F., Land, R., & Baillie, C. (Eds.). (2010). *Threshold concepts and transformational learning*. Rotterdam, The Netherlands: Sense.
Nemirovsky, R. (2011). Episodic feelings and transfer of learning. *Journal of the Learning Sciences, 20*(2), 308–337.
Nersessian, N. J. (2005). Interpreting scientific and engineering practices: Integrating the cognitive, social, and cultural dimensions. In M. E. Gorman, R. D. Tweney, D. C. Gooding, & A. P. Kincannon (Eds.), *Scientific and technological thinking* (pp. 17–56). Mahwah, NJ: Lawrence Erlbaum Associates.
Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.
Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
Nokes, T. J. (2009). Mechanisms of knowledge transfer. *Thinking & Reasoning, 15*(1), 1–36.
OECD. (2007). *Understanding the brain: The birth of a learning science*. Paris, France: Centre for Educational Research and Innovation.
Ohlsson, S. (1995). Learning to do and learning to understand: A lesson and a challenge for cognitive modelling. In P. Reimann & H. Spada (Eds.), *Learning in humans and machines: Towards an interdisciplinary learning science* (pp. 37–62). London, UK: Pergamon Press.
Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20–40. doi:10.1080/00461520802616267.
Ohlsson, S. (2011). *Deep learning: How the mind overrides experience*. Cambridge, MA: Cambridge University Press.

Özdemir, G., & Clark, D. B. (2007). An overview of conceptual change theories. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(4), 351–361.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Patel, V. L., Arocha, J. F., & Zhang, J. (2005). Thinking and reasoning in medicine. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 727–750). Cambridge, MA: Cambridge University Press.

Pecher, D., & Zwaan, R. A. (Eds.). (2010). *Grounding cognition: The role of perception and action in memory, language, and thinking*. New York, NY: Cambridge University Press.

Perkins, D. (2006). Constructivism and troublesome knowledge. In J. H. F. Meyer & R. Land (Eds.), *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge* (pp. 33–47). London, UK: Routledge.

Perkins, D. (2007). Theories of difficulty. *BJEP Monograph Series II, Number 4 – Student Learning and University Teaching, 1*(1), 31–48.

Perkins, D. N., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher, 18*(1), 16–25. doi:10.3102/0013189x018001016.

Perry, L. R. (1965). Commonsense thought, knowledge and judgement and their importance for education. *British Journal of Educational Studies, 13*(2), 125–138.

Philip, T. M. (2011). An "ideology in pieces" approach to studying change in teachers' sensemaking about race, racism, and racial justice. *Cognition and Instruction, 29*(3), 297–329. doi:10.1080/07370008.2011.583369.

Redish, E. F. (2004). *A theoretical framework for physics education research: Modeling student thinking*. Proceedings of the International School of Physics, "Enrico Fermi" Course CLVI, Amsterdam.

Rogoff, B., & Lave, J. (Eds.). (1984). *Everyday cognition*. Cambridge, MA: Harvard University Press.

Rommetveit, R. (1978). On negative rationalism in scholarly studies of verbal communication and dynamic residuals in the construction of human subjectivity. In M. M. P. Brenner & M. Brenner (Eds.), *The social contexts of method* (pp. 16–32). London, UK: Croom Helm.

Säljö, R. (1991). Piagetian controversies, cognitive competence, and assumptions about human communication. *Educational Psychology Review, 3*(2), 117–126. doi:10.1007/bf01417923.

Savin-Baden, M. (2000). *Problem-based learning in higher education*. Buckingham, UK: SRHE/Open University Press.

Schank, R. C., & Abelson, R. P. (1977). *Scripts, plans, goals, and understanding: An inquiry into human knowledge structures*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Schatzki, T. R., Knorr-Cetina, K., & von Savigny, E. (2001). *The practice turn in contemporary theory*. London, UK: Routledge.

Schraw, G. (2006). Knowledge structures and processes. In P. A. Alexander & P. Winne (Eds.), *Handbook of educational psychology* (pp. 245–263). Mahwah, NJ: Lawrence Erlbaum Associates.

Schwartz, D. L., & Bransford, J. D. (1998). A time for telling. *Cognition and Instruction, 16*(4), 475–522. doi:10.2307/3233709.

Schwartz, D. L., Varma, S., & Martin, L. (2008). Dynamic transfer and innovation. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 479–508). New York, NY: Routledge.

Scribner, S. (1985). Knowledge at work. *Anthropology and Education Quarterly, 16*, 199–206.

Scribner, S. (1997). *Mind and social practice: Selected writings of Sylvia Scribner*. Cambridge, NY: Cambridge University Press.

Siegel, D. J. (2012). *The developing mind: How relationships and the brain interact to shape who we are* (2nd ed.). New York, NY: The Guilford Press.

Sinatra, G. M., & Pintrich, P. R. (Eds.). (2003). *Intentional conceptual change*. Mahwah, NJ: Lawrence Erlbaum Associates.

Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis*. New York, NY: D. Appelton-Century.

Smith, L. B. (2005). Cognition as a dynamic system: Principles from embodiment. *Developmental Review, 25*(3–4), 278–298. doi:10.1016/j.dr.2005.11.001.

Smith, L. B., & Gasser, M. (2005). The development of embodied cognition: Six lessons from babies. *Artificial Life, 11*(1–2), 13–29. doi:10.1162/1064546053278973.

Sousa, D. A. (2011). *How the brain learns* (4th ed.). Thousand Oaks, CA: Corwin.

Sterelny, K. (2003). *Thought in a hostile world: The evolution of human cognition*. Oxford, UK: Blackwell.

Sterelny, K. (2012). *The evolved apprentice: How evolution made humans unique*. Cambridge, MA: MIT Press.

Sternberg, R. J. (1985). *Beyond IQ: A triadic theory of human intelligence*. Cambridge, UK: Cambridge University Press.

Sternberg, R. J. (2004). *Wisdom, intelligence, and creativity synthesized*. Cambridge, NY: Cambridge University Press.

Stewart, J., Gapenne, O., & Paolo, E. A. D. (Eds.). (2010). *Enaction: Toward a new paradigm for cognitive science*. Cambridge, MA: MIT Press.

Sweller, J., van Merrienboer, J. G., & Paas, F. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251–296.

Szymanski, M. H., & Whalen, J. (Eds.). (2011). *Making work visible: Ethnographically grounded case studies of work practice*. Cambridge, MA: Cambridge University Press.

Turnbull, D. (2000). *Masons, tricksters and cartographers: Comparative studies in the sociology of scientific and indigenous knowledge*. Abingdon, OX: Routledge.

Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience* (6th ed.). Cambridge, MA: MIT Press.

Vera, A. H., & Simon, H. A. (1993). Situated action: A symbolic interpretation. *Cognitive Science, 17*(1), 7–48.

Vosniadou, S. (Ed.). (2008/2013). *International handbook of research on conceptual change* (1st and 2nd eds.). New York, NY: Routledge.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science, 18*(1), 123–183. doi:10.1207/s15516709cog1801_4.

Vosniadou, S., & Ioannides, C. (1998). From conceptual development to science education: A psychological point of view. *International Journal of Science Education, 20*(10), 1213–1230. doi:10.1080/0950069980201004.

Wagner, J. F. (2006). Transfer in pieces. *Cognition and Instruction, 24*(1), 1–71.

Wagner, J. F. (2010). A transfer-in-pieces consideration of the perception of structure in the transfer of learning. *Journal of the Learning Sciences, 19*(4), 443–479.