Meaning:
Multiple Representations, Computation & Instruction

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ABSTRACT

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The development of a computer program that models human approaches to problem solving, studies of human perceptual processes, an account of the foundations of language and meaning -- any of these may inform theories of learning and instruction. Sources for ideas about education are legion; some are complementary, and others conflicting. We can develop models from multiple perspectives, applying a range of concepts to problems in the field. The trick is never to be tied to a single way of seeing and solving problems. Too heavy an anchor can keep our minds from wandering freely to novel ideas and approaches.

Models are developed from metaphors, which are means of creating new representations of the world. These representations are vital sources of information. We cannot know the world as it 'really' is. Rather, we try to access features of the world through representations created and shared with others. The computational model is one such source of representations. It suggests certain ways of thinking about the mind. It emphasizes some aspects, and downplays or even hides others.

No one model can account for all features of a phenomenon, particularly a complex one. One limitation of the computational model is its inability to simulate the creation of

multiple representations. These multiple representations, as acknowledged earlier, are essential means of knowing the world. It is a weakness of importance to people interested in the creation and manipulation of knowledge, which includes instructional theorists and researchers. In essence, the computational model must be supplemented with other models, especially ones that *can* account for the mind's ability to create and value multiple representations.

One day the husband of a woman who was being painted by Picasso called at the artist's studio. 'What do you think?' asked the painter, indicating the nearly finished picture. 'Well...' said the husband, trying to be polite, 'it isn't how she really looks.' 'Oh,' said the artist, 'and how does she really look?' The husband decided not to be intimidated. 'Like this!' he said producing a photograph from his wallet. Picasso studied the photograph. 'Mmm...' he said, 'small, isn't she?'

Charles Hampden-Turner, *Maps of the Mind*, p.8

Sometimes elegantly structured, usually self-confirming, our models are like the headlights of a car, designed to light our way. Whatever is illuminated becomes our truth, and we organize our lives around it. But this light we create can also blind us. Too often we are blinded into believing that our models are the whole reality, forgetting that they are simply useful fact/fantasy coping devices.

Gordon MacKenzie, *Orbiting the Giant Hairball*, p.163

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Introduction

The mind of a learner is a notoriously difficult thing to model. In recent years, cognitive scientists have been successful in modelling certain features of the mind with computational systems, both formalist and connectionist. In the wake of these successes, computational models have been adopted by theorists from many fields, including education. The question is, in which contexts and to what extent is the computational model an adequate representation of the mind?

Part I of this thesis concerns the nature of our knowledge of the world and the ways in which we create different perspectives or interpretations of phenomena. I argue that we cannot know the world 'as it is', but that there remains nonetheless a correspondence between reality and our knowledge of it. This correspondence, due to the relationship between the subject and the object of knowledge, as well social negotiations among members of a linguistic community, prevents any slide into relativism. A place is therefore retained for the critical evaluation of interpretations. Though we should not settle on a single interpretation, there are criteria for the selection of those that are more 'right' than the others.

Part II puts these ideas into practice. The computational model is necessarily limited. No model can account for all the features of its subject. It can happen, however, that we conflate the model with the phenomenon it models. To avoid this confusion, the characteristics of the model must be made explicit, and its strengths and weaknesses assessed. The computational model is weak with respect to the representation of knowledge. Specifically, it does not account for the creation and manipulation of multiple representations. As argued above, different perspectives are keys to meaning. The computational model may be one 'right' account of the mind. There are others, specifically others that can account for our ability to cope with several 'right' accounts. This ability, I argue, is a valuable aspect of education. Students should be taught the value and uses of multiple interpretations of phenomena in the world. This position has certain features in common with constructivist theories, and the similarities are briefly discussed.

My conclusions are presented in both discursive and narrative forms. In essence, I claim that any single model of the mind is bound to have certain limitations, and that one limitation inherent in the computational model is an inability to account for multiple representations of phenomena. If several 'right' interpretations are necessary for the fullest possible understanding of a phenomenon, then the computational model, on both levels, must necessarily be supplemented by other models of the mind.

Chapter 1 Fashioned worlds

A flight of fancy?

Imagine that things are not as they appear, that the world is not really as we perceive it. Is this a philosopher's fancy, a dreamy delusion? We trust our senses to reveal the world as it really is. We use the evidence of our senses to manipulate objects and the relationships among them.

We believe that our perceptions are signs of real objects and properties, existing independently of us. Our senses are tools we use to extract objective information from the world. Perception transmits sensations faithfully and cleanly.

But why trust the world actually is as it appears? In the twentieth century, we do accept that matter is composed of atoms. That means we believe that most of matter is empty space, although it doesn't seem that way to us (in fact, we don't usually act with that in mind, do we?). We know we cannot always trust the evidence of our senses.

In fact, the world is *not* as it appears. We create different versions of the world, first through perception, and then language.

Perception

Objects and relationships are not perceived independently of our prejudice, perspective, way of seeing. Our senses select, emphasize, obscure and organize data from the enveloping world.

> The eye comes always ancient to its work, obsessed by its own past and by old and new insinuations of the ear, nose, tongue, fingers, heart, and brain. (Goodman, 1988, p.7)

The eye builds what we see. The signals sent by the senses have already begun to be interpreted before they reach the brain (Bronowski, 1971). The eye, for instance, does not send neutral data along the optic nerve, a mere record of lights and darks. It sends messages about shapes, because the neurons connected to the eye are specifically designed to recognize particular patterns. Before sense data reaches the brain, it has already been partly interpreted as a signal, of a predator perhaps, or of prey. A rabbit is sensitive to up and down movements on the horizon, and is quick to flee. A frog's tongue darts out to catch a fly just as it senses a spot moving in its field of vision.

Our senses, therefore, provide us with interpretations, not raw images. They transmit information rather than data. Out there in the world, however, there *is* data. There are things existing in the world upon which our senses act. I do not invent all but myself, in solipsistic angst.

There can be no self, or subject, without an object, and no object without a subject (Arendt, 1978; Ortega y Gasset, 1960/1964).

> ...I am that which sees the world and the world is that which is seen by me. I exist for the world, and the world exists for me. (Ortega y Gasset, p.199)

That the self is conscious necessarily implies it is conscious *of something*. Even if I hear a voice in a dream, it is still the object of my dream. My self exists because it dreams of voices, and the existence of the voices depends in turn on me.

Objects *do* exist independently of our perceptions, but because self and object are so intimately related, we can know nothing of an object's autonomous nature. Each object I perceive bears a certain relationship to me, and becomes a functional object of "my life" (Ortega y Gasset). I impose my vision on each sight, my hearing on each sound. There is no access to an object as it is before it is perceived.

Because we cannot perceive objects as they actually are, they can be seen from a variety of perspectives. I come to understand an object because of how "it-seems-to-me" (Arendt). Each of us can perceive an object in different ways, depending on prior experience and the context in which the object is met.

Different perspectives are possible since appearances conceal as they reveal (Arendt). As I perceive one aspect, others are necessarily hidden from me. To take a concrete example: I can look at a tree from the street, from another a tree, from space, from an anthill, from the park, but I can only observe from one position at a time. Seeing from one perspective means I do not see from others, at that moment. Other points of view are possible, however, as soon as I change my perspective[1].

Although there are innumerable perspectives from which we might perceive objects and their interrelationships in the world, we do tend to share certain perspectives as members of a community. As an individual rabbit will interpret movement on the horizon as a sign of a predator, so will most if not all rabbits. Constructions of the world, our perceptions of objects, are not free from constraint. Our inclination to see objects in similar ways is due to shared context within a community. It is this shared context, these shared beliefs, that lead us to believe we are seeing the world 'as it is'.

The constraint on possible interpretations means there are many "right versions" of the world (Putnam, 1992). Many constructions are possible (that is, can be thought of or imagined), but some of these are more 'right' than others.

Language

We construct versions of the world through perception. These versions are also structured by language.

We use words to order our perceptions, for ourselves and for others. Words carve the world into classes, so we can sort the objects and relationships we perceive into different groups. 'Table' and 'chair' are each classes of 'furniture'. We can usually agree, with other members of the linguistic community, on which kinds of furniture are chairs, and which are tables. We all tend to use these words in the same way, and again we are led to believe that these concepts are somehow natural, or fixed, that the essence of 'chair' is clearly and definably different than the essence of 'table'. We have a great fondness for classificatory schemes[2].

Wittgenstein (1953/1988) argues, however, that concepts have no definable essence. There is no set of necessary and sufficient conditions by which we can characterize 'chair' or 'table'. Think of how you would describe to someone what a chair is. As soon as you choose a set of features by which to recognize an example of 'chair', you are bound to encounter an instance that doesn't fit your definition. The Cesca chair has few characteristics in common with the Monroe chair, and fewer still with the Pedestal chair (Gordon, 1996). Yet we can still recognize each of these different designs as examples of chairs.

What each of these chairs does share is a certain family resemblance (Wittgenstein). There is a group of properties shared among chairs, but different chairs will have different subsets of these properties.

Some chairs are more chair-like than others. A standard kitchen chair with four legs, for example, may seem a better example of a chair than a beanbag chair. In this case we can call the former a prototype, an exemplary instance of 'chair', because it has many of the properties we think a chair should have. In the same way we consider a robin a prototypical bird, rather than an ostrich or a penguin, although each shows sufficient family resemblance to be considered a bird[3].

Since a concept cannot be defined according to a set of necessary and sufficient conditions, how can we determine its meaning? Wittgenstein argued that in most cases the meaning of a term is derived from its use in a particular context. We learn what a word means by observing how it is used by experienced speakers of the language.

The meaning of a term, or phrase, can therefore vary, as different people use it in different contexts. As in the case of perception, there are limits to how a word can be understood, which depend on the shared practices of the linguistic community. Because the meaning of a word or phrase depends on how it is used, however, it is never fixed. It will change to reflect the needs and experiences of the speakers and of the listeners. These changes allow us to construct the world in a variety of ways, since we cannot know reality antecedent to the concepts we use to structure it. Objects and relations in the world literally *become* as we come to perceive and speak of them.

> Everything is gathered by him as part of an altering harmony. He sees her in differing hours and locations that alter her voice or nature, even her beauty, the way the background power of the sea cradles or governs the fate of lifeboats. (Ondaatje, p.219)

Chapter 2 Metaphor: Creating alternative representations

> Why do we model reality and represent it as a myth, metaphor, or scientific theory? (Pagels, 1988, p.88)

Metaphor is a specific instance of the work done by language. It re-orders concepts in new and often provoking ways to challenge established perspectives.

This is not an esoteric point. Introducing new metaphors can be an effective means of solving practical problems. Changing perspective through metaphor, for example, can help resolve difficult issues of social policy (Schön, 1993). We tend to focus on those aspects of a problem situation that fit a certain metaphor, or frame. This focus predetermines the set of possible solutions. A new metaphor can sort concepts in a fresh way, revealing possible solutions previously inaccessible.

This chapter describes the nature of metaphor and the means by which it effects these transformations of perspective.

Accounts of metaphor[4]

In the canonical work *Models and Metaphors*, Black (1962) argues that certain complex metaphors are interactive, a claim he credits to I. A. Richards. An interactive metaphor alters our understanding by transforming one subject through its relation to another.

The primary subject is the literal term (or set of literal terms) which acts as the frame of the statement. The secondary subject is the focus, the metaphorical term (or set of terms) introduced to restructure the frame.

In the following example[5]:

> Once erected, her thoughts were statues in the garden and she passed through, taking a good look as she went on her way. (Lispector, 1944/1990, p.18)

the primary subject is 'her thoughts' and the secondary subject 'statues in the garden'. 'Statues' is used here to change the way we perceive 'thoughts'.

Each subject is structured by an implication-complex. The implication-complex is the set of properties and relations belonging to each subject. Through the interaction of the two complexes, structural similarities are generated and a certain isomorphism becomes apparent (Black, 1962 & 1993). Interactive metaphors do not simply highlight similar features already evident. According to the strong creativity thesis, the connections only exist *after* they are perceived through the cognitive action of the metaphor.

> It would be more illuminating in some of these cases to say that the metaphor creates the similarity rather than to say that it formulates some similarity antecedently existing. (1962, p.37)

In the case of the example above, supposing it is an interactive metaphor, a structural similarity is created between 'statues' and 'thoughts' that did not exist before. This similarity provokes us to order our concept of 'thoughts' in a new way, based on the implication-complex belonging to the concept of 'statues'. The complex would include such properties as 'rigidity' and 'coldness', and possibly even 'beauty' or 'constancy', depending on how these properties might interact with the properties of the primary subject, 'thoughts', in the context of the passage.

It is not only the primary subject that is altered by interaction with the secondary subject. The secondary subject is also transformed; the interactive process is reciprocal (Black, 1962 & 1993).

Certain properties of the implication-complex belonging to the secondary subject, 'thoughts', induce change in the concept of 'statues'. For example, when considering statues as representations of thoughts and ideas, we may attribute a certain animation to these stone figures. The metaphor generates much of its force from the interaction between animate and inanimate entities, playing with one of the most basic natural prototypical dichotomies with which we sort the world (Mac Cormac, 1985).

Mac Cormac developed the concepts of epiphor and diaphor, based on the work of P. Wheelwright, to come to grips with the attribution of truth and falsity[6] to metaphorical statements. Mac Cormac argues that our common two-value truth system is inadequate;

he proposes a four-valued logic: truth, epiphor, diaphor and falsity. We can therefore ascribe truth to statements in varying degrees.

> The more suggestive the metaphor, the greater the degree of falsity; the more expressive of analogy, the greater the degree of truth. (p.30)

The more expressive metaphors are epiphors. They are more true than false, because they tend to emphasize similarities. Diaphors, on the other hand, are more false than true. They are more daring, suggesting new possibilities for exploration.

Diaphors are Black's interactive metaphors, creating new and provoking juxtapositions of complexes rather than highlighting obvious resemblances. As diaphors become accepted reflections of objects or relationships through repeated use, however, they will tend to become epiphors, and sometimes even truths. Other diaphors, which do not capture important new insights, will slide into disuse and thus falsity. Sometimes this happens because the metaphor is arbitrary rather than revealing, as in the following example from the rock-hard science of physics:

> Take the labeling of quarks as "colored", "strange", "charmed", and more recently "beautiful" and "true". Some debate has taken place as to whether these descriptions of quarks are metaphoric or arbitrary. (Mac Cormac, p.219)

If a metaphorical description is no more than whimsical, the label may remain but there will be no real interaction between complexes and so no meaningful discovery of isomorphism.

The transition from diaphor to epiphor to truth is often considered a gradual decline into trite banality, but that depends on the domain of the metaphor (Boyd, 1993). Literary metaphors tend to expire after repeated usage. Scientists, however, profit from continued exposure to and investigation of a particular metaphor, as they work to uncover further features of similarity or dissimilarity.

Another way to look at metaphor is through the Wittgensteinian approach to concept definition. Recall that there are no necessary and sufficient conditions by which to define a term. Instead we learn the meaning of a term as it is used in different contexts. To teach a new word we focus on the prototypical instances, the robins and the kitchen chairs, because they are most typical of their respective categories. Each is most representative of its class.

Membership is then extended to other examples, such as ostriches and beanbag chairs, which share sufficient features to belong to the category. The final, most distant extension of a concept is its metaphorical application to other realms. Picture these extensions in colour. The link from concept to prototype would be a vibrant red, to the more distant examples a moderate mauve, and finally, to the metaphorical uses, a soft and gentle blue.

Metaphor and theory

Boyd launches his account of theory-constitutive metaphor based on the failure of necessary and sufficient conditions to secure the definition of certain concepts. He does not, however, rely on prototypical instances. Boyd looks at homeostatic property cluster kinds, a class of concepts whose definition depends instead on identifying relevant causal powers; that is, some concepts must be defined ostensively, by pointing out the mechanisms responsible for the occurrence of certain properties[7].

This emphasis on causal relationships is important because the goal of scientific research, according to Boyd, is:

> the task of accommodation of language to the causal structure of the world. (p.483; italics deleted)[8]

Metaphor is an excellent means of exploring causal relations when the empiricist idealization of necessary and sufficient conditions breaks down. This makes metaphor an irreplaceable research tool not only in the early, pre-theoretical stages of a science, but in the theoretical development of mature sciences as well. Metaphors work at the core of science (e.g., Smith, 1994); they provide the grist for new theories at any stage of a science.

Metaphor determines not only which questions can be answered but which questions can even be raised (Sternberg, 1990), just as the way in which we approach a problem determines which solution paths are available.

Understanding the aim and scope of a theory depends on a frank appraisal of the underlying metaphor. For example, Sternberg describes several theories of intelligence based on different metaphors of the mind. Each theory approaches intelligence from a different perspective, carving a unique territory. The maps cannot be shared. A feature that is clearly apparent from one perspective may disappear from another view.

Because intelligence is such a complex phenomenon, it does not fall within the purview of any one theory based on a single metaphor of the mind. Researchers who assume their theory applies to the whole of a phenomenon are victims of synecdoche (Sternberg); that is, they assume their theoretical portrait (a part) can account for the entire multifarious phenomenon (the whole).

A metaphor can also be considered a paradigm, in the sense elucidated by Masterman (1987). In her exegetical account and occasional critique of *The Structure of Scientific Revolutions*, Masterman describes the primary meaning of 'paradigm':

> A paradigm has got to be a concrete 'picture' used analogically; because it has got to be a 'way of seeing'. (p.76)

A paradigm is a construct used by practitioners to solve scientific research puzzles. The double-helix model[9] of DNA developed by Watson and Crick, for instance, was a groundbreaking perspective, a 'concrete picture' that launched a novel approach to the study of genetics. A metaphor operates in the same way, by importing a structure from one realm into another, as DNA was perceived in terms of a winding linked staircase. As Watson and Crick cautioned, "this figure is purely diagrammatic" (Purves & Orians, p.303). That is, do not identify DNA with the model; rather, the model is an aid, a 'way of seeing'[10].

Once a construct has kickstarted normal science by providing the means to solve puzzles, it subsequently grounds the set of habits followed by members of the research community. It also serves as the foundation for the metaphysical world view adopted by these practitioners. Here is the profound impact of metaphor; it is a fundamental means of structuring the world, by scientists as well as poets.

Combinative accounts

There are, as we saw earlier, many different 'right' ways to structure the world. A range of metaphors gives us fresh understandings, but these may not be harmonious. Each metaphor is a gazetteer, charting the same plot in a distinctive way, highlighting some features while hiding or downplaying others, but the charts may turn out to be incommensurable.

The relation between different metaphorical perspectives need not be so extreme. Lakoff and Johnson distinguish between consistent and coherent metaphors. Consistent metaphors are rare. They form a single image of a phenomenon, focusing on the same features. Coherent metaphors, however, share some overlap but tend to present divergent pictures of a phenomenon.

Sternberg argues that separate views must be carefully melded, so they may complement rather than heedlessly detract from one another.

> We will understand intelligence fully only when we find a way of integrating metaphors without callously mixing them. (p.17)

There is great value in exploring complex phenomena from many different perspectives, to uncover attributes that would otherwise remain hidden. These perspectives should work together rather than at the expense of each other so the fullest possible understanding may emerge.

Chapter 3 Spatial representations: Applications

Spheres and planes

In the first two chapters, I argued that there are many different ways to describe or think about 'how things are'. Some of these representations may be better than others, but we cannot assume a single correct perspective. Of this view, however, you remain unconvinced. Are there unique representations of which we ought not doubt?

In this chapter, we will explore two means of representing space: the arts of map-making and of linear perspective. Each involves a transposition from three to two dimensions, yet we usually assume that each renders space faithfully. We will see that this assumption is problematic.

Cartography

Ovenden (1995) describes a current, quite fractious debate among cartographers: to what extent is an atlas an objective representation of the world[11]? The most common map of the world is the atlas created by Gerhardus Mercator in 1538 (Ovenden). The Mercator map is the standard atlas seen in classrooms and books. If you were to imagine a two-dimensional map of the world in your mind at this moment, it's likely you would be looking at a Mercator projection.

But why do we refer to maps as 'projections'? A map is a projection of three-dimensional features onto a two-dimensional surface. This is by no means a straightforward process, as described by the chief cartographer in the introduction to the Peters atlas:

> Anyone who has ever tried to peel an orange and press the peel into a continuous flat piece without tearing will have grasped the fundamental impossibility that lies at the heart of all cartographic endeavour... (Peters, 1989, p.3)

The question is, which features of the world do we want to preserve, at the expense of which others? If you design a map to reproduce the shapes of the continents, the relative areas will be off. If, on the other hand, the map is to be faithful to area, the shapes will necessarily be distorted. It is impossible to preserve our conception of a three-dimensional sphere in two dimensions.

What determines which features are preserved? It depends on how the map will be used (recall the Wittgensteinian account of concept definition based on the context of use). The Mercator map preserves the relative shapes of the continents, because this map was to be used for navigational purposes. Mercator designed his atlas during the period of Europe's vast colonial expansion, when the covetous rulers sought the best routes to their conquests.

But the Mercator map projects more than the shapes of the continents. It also represents a perspective of the world that developed as the European nations were building their empires. This map embodies European domination of the world (Peters).

The Mercator map, through the preservation of shape, seriously distorts the relative areas of the continents. Compare the sizes of Europe and South America on the Mercator map. Would you imagine, by looking at this map, that South America is almost twice the size of Europe (*The Peters Projection*)[12]?

The Mercator map projects more than shapes; it projects power. It implicitly reflects the political and economic domination of the north and the west over the south and the east. It has remained the standard cartographic reference just because it illustrates and so helps preserves that power.

Arno Peters, a German cartographer, designed a new atlas in 1972 (Ovenden). The Peters atlas is an equal-area projection; in other words, Peters chose to value relative area over shape. At first glance the map looks a little odd. Ovenden quotes a critic of Peters, who complains that Africa looks like laundry hung out to dry.

Peters, however, is not as concerned with preserving continental contours as with revealing that maps are social constructs.

> This atlas is unsuitable for some purposes. A world atlas like this one is not designed to guide the motorist, or to replace the inexpensive detailed road map; nor is it intended as an aid for local geography. It offers, instead, a comprehensive global view. (Peters, p.2)

Peters argues that the Mercator map supports the exploitation of the third world by the developed countries (Ovenden). His map is designed to help redress the imbalance of power by redistributing area. The Peters map emphasizes relative size to reflect value, and the result is dramatic.

As Ovenden and Peters argue with conviction, a map is a *subjective* representation of the world. "Cartography, then, can be defined as not only the drawing of maps, but the making of worlds." (Ovenden, p.30)

What seems funny now, when I look at the map, is that the northern hemisphere is always on top. Picture the world on its head. It doesn't look like *our world* anymore, does it?

Linear perspective

Panofsky (1927/1997) devoted *Perspective as Symbolic Form* to an evaluation of perspective in the history of Western art, from Antiquity to the Renaissance. He argues that the perspective we choose to adopt defines our conception of three-dimensional space. Perspective is a means of determining rather than passively reflecting the nature of space.

The modern geometrical construction of linear perspective, perfected during the Renaissance period, represents space as infinite, unchanging and homogeneous. It is a mathematization of space idealized by the Cartesian coordinate system.

Psychophysiological data, however, do not always agree with such a representation of three dimensions.

The system of linear perspective depends on two basic premises: (1) the viewer is looking with a single eye that does not move, and (2) the "planar cross section of the visual pyramid"[13] approximates the image projected onto the eye (Panofsky, p.29).

Linear perspective presupposes a vanishing point, the apex of the visual pyramid. That is the point at which all the angles in a painting, for example, converge. From the vanishing point ('behind' the painting, for example), the visual rays extend out to the flat surface of the painting (which is the planar cross section) and onto the surface of the eye, creating the illusion of three-dimensional depth on a plane.

There is a series of problems with the premises on which linear perspective is based. Here are two. First, we look at paintings with two eyes, both of which are always moving. Second, and more interesting in terms of this discussion, is the fact that the retina is a *curved* surface. The optical image is projected onto a curved surface and not a flat one.

> Finally, perspectival construction ignores the crucial circumstance that this retinal image...is a projection not on a flat but on a concave surface. Thus already on this lowest, still prepsychological level of facts there is a fundamental discrepancy between "reality" and its construction. (Panofsky, p.31)

This is the reason why objects on the margins of the visual field tend to curve. You can compare, for example, the way a series of columns is drawn to how it is seen. According to modern perspectival construction, all the columns would be drawn as perfectly straight lines. If a person actually looked at those columns, however, they would tend to look increasingly curved the further they were from the centre of the visual field.

Magnitudes are also distorted when objects are sized according to linear perspective. Antique perspective, which recognized the optical field as curved rather than flat, was actually more accurate in representing size, because apparent size was determined as a function of the angle subtended by an object rather than simply the distance of that object from the viewer. It's a subtle point, but it makes a noticeable difference in the appearance of objects and the relationships among them.

Once again, the difficulties of representing three-dimensional space in two dimensions is apparent, and it is clear that linear perspective is not *the* single, accurate representation of space, since:

> ...the creation of a perspectival image [is], strictly speaking, an impossible task, for a sphere obviously cannot be unrolled on a surface. (Panofsky, p.36)

Certain features are lost, while others are gained. What is gained in this case is of considerable value in the world we have created, a world which depends on an abstract conception of space as systematic and mathematical. These features, however, are a product of the spatial system that is adopted, rather than the reverse.

Planes and spheres

This brief segue into the arts of cartography and of linear perspective was intended to drive home the main argument of the preceding chapters, namely that representations are adopted to create a way of seeing for a certain purpose. Other purposes may require other representations, and a new perspective may unearth some questionable axioms.

Chapter 4 Knowledge representation

Models of the mind

We have forever likened the mind to other things, in attempts to ferret out its nature.

The Ancient Greeks were very interested in the nature of the mind. Plato likened the mind to a political community, while Aristotle, his more practically inclined student, claimed that we use our minds as we do our hand (Turbayne, 1972).

Later philosophers explored other metaphors. Descartes described the mind as the pilot of the ship (the body), and Hume wrote about the mind as theatre (Turbayne).

In more recent history, however, Western society in particular has been enveloped by a wonder of technology, as evidenced in part by twentieth-century accounts of the mind.

Mac Cormac and Bronowski each offer a brief history of our attempts to account for human behaviour and the mind in terms of machines. We have been likened to clocks and watches, to telephone exchanges and other such devices. But the most common comparison currently being studied is the information processing, or computational, model of the mind:

> ...a concern with exploring analogies, or similarities, between men and computational devices has been the most important single factor influencing postbehaviorist cognitive psychology. (Boyd, 1993, p.487)

The computational model

Although research began with the application of anthropomorphic concepts and terminology to computer functions and structures, this perspective was soon inverted. As the implications of the metaphor of computer as brain were explored, computational concepts were reflected back on human thought processes. Studies of human and machine cognition began to inform each other.

Using computational processes and structures that were originally simulations of human cognition to subsequently guide studies of how the mind works is a curiously circular piece of logic (e.g., Scheffler, 1991). It's like translating a play from one language into another and then back again; many of the words and especially the expressions could shift considerably in meaning[14]. But it is also, as Mac Cormac argues, an excellent example of an interactive metaphor.

> When we claim metaphorically that "computers think", not only do machines take on the attributes of human beings who think...but "thinkers" (human beings) take on the attributes of computers. (p.10)

Our perceptions of both computers and minds are transformed as they are compared, as the findings in such fields as artificial intelligence, neurophysiology and psychology are correlated and fused. In what senses do computers think as we do? In what senses do we think as computers do? What structures and functions might we share?

Researchers must take care not to limit their thinking to the level of technology currently available to them. As Arbib (1989) warns, it is a common error to liken human brains to computers as they are conceived at a particular moment. Study of the mind is then unfairly limited by the comparison. For example, many researchers once assumed that brains must operate in series, as then-current computers did. Those fields focusing on cognition, both human and machine, were thus constrained by a particular structural set-up. The subsequent shift to parallelism in the connectionist systems allowed those conceptual constraints to be lifted.

> ...we are not trying to reduce humans to the level of extant machines, but rather to understand the ways in which machines give us insight into human attributes. (Arbib, p.6)

In the next section of this chapter, we will explore the features common to serial (formalist) and parallel (connectionist) systems.

Mac Cormac outlines 'cognition as computation', or the set of metaphors describing the relations between human and machine thought, as follows:

> Under the computational metaphor the brain can be viewed as a computational device similar to a computer, and the mind emerges as a series of programs by means of which the brain functions. (p.9)

The brain is considered hardware, the structure of neuronal connections within which the mind (software) operates.

The basic metaphor is extended by different researchers over a range of features, and to various extents. The more challenging and provoking the relations drawn, the more diaphoric the metaphor. As Mac Cormac argues, the more diaphoric metaphors tend to be more fruitful and more engaging because the interpretations are considerably more subtle and intriguing. They are suggestive of new possibilities rather than more mundane similarities.

Metaphors, and especially diaphors, however, can mislead as well. Certain attributes are hidden, or downplayed, while others loom large. Given that the computer model has become the dominant approach to understanding the mind (e.g., Boyd, 1993 and Driscoll, 1994), it is critical to look carefully at the metaphor, to determine its implications.

Formalist and connectionist systems

I am interested in the different ways knowledge can be represented. This is the perspective from which I will examine the computational model. There is considerable debate, however, about whether there is one such model, or two. The following discussion will outline the basic features of the computational model by comparing two different systems, formalist and connectionist.

Formalist systems are von Neumann machines. They operate in series through syntactic operations on structures, or symbols (Boden, 1988). Knowledge is represented by the operations, or procedures, as well as the symbols themselves[15].

Connectionist systems work a little differently:

> Connectionist systems are made up of locally communicating units functioning in parallel, where... the state of any one unit depends largely on the states of its neighbors. (Boden, 1987, p.482)

In a connectionist system, representations are distributed over a network of units, where a distribution is a function of the connection weights among the units. Symbols and procedures don't seem to be explicitly represented in connectionist systems. Rather than symbols, there are various patterns of excitation across an entire network, patterns based on equilibria reached by connection weights. Thus the system seems to represent cognition at the subsymbolic rather than the symbolic level (e.g., Pagels, 1988). There don't appear to be rules either, at least not as understood in formalist terms. There is no list of instructions in a program. Instead there are excitatory and inhibitory connections hardwired[16] between units.

The question is, how similar are these two architectures? Is there a single computational model, or are these two systems incommensurable with respect to knowledge representation? Boden (1988) argues that formalist and connectionist systems are sufficiently related to be considered (quite distant) cousins rather than distinct paradigms.

Boden cites several reasons for her claim. In Kuhnian terms, the pivotal influence of the seminal work by McCulloch and Pitts on both research programmes suggests that formalist and connectionist systems are developing within the same computational paradigm[17].

With respect to the representation of knowledge, Boden suggests that the deceiving difference lies in whether the representations are explicit or implicit[18]. In general, knowledge is represented explicitly in formalist systems, and implicitly in connectionist systems. Boden further argues that knowledge that is implicitly coded in a connectionist system can cause behaviour that is rule-governed, even though those rules are not explicitly represented within the system:

> In addition, connectionist systems develop patterns of associative weights which may cause the system to behave *as though* it were following rules of a type which could be (and often are) made explicit in a von Neumann machine. (p.258)

Whether the knowledge is represented explicitly or implicitly, Boden claims that at heart, both systems manipulate symbols and rules. In the case of formalist systems, this description is straightforward. But, as Boden argues, the operation of connectionist systems can also be described in terms of symbols and rules.

There *are* rules that govern the modification of connection weights between the units as the system settles into a state of equilibrium. The units are wired together in a particular way, a way that embodies theoretical constraints on how information will be processed.

> But [the] function [of these rules] in determining the information-processing within the system justifies their being regarded as a (different) type of algorithm. (Boden, 1988, p.255)

Boden further argues that we can speak of symbols within connectionist systems as well, though again they are different than the symbols of a formalist system. While formalist symbols are separate, distinct structures, a connectionist symbol is the pattern of activity distributed over the network as a whole. Different patterns are different symbols, and their properties can reflect abstract entities, relationships and events.

Boden argues for an equivalence of formalism and connectionism on the basis of shared structures and processes. Equivalence is more formally defined by the Conventionalism Thesis, according to which two theories are equivalent if they make the same predictions given the same information (Shaw, 1984). That is, equivalent theories produce the same outputs from the same inputs, even if they reach these outputs by different means.

It *is* possible to translate results of a formalist system to a connectionist one, and vice versa (Boden). Formalism and connectionism are therefore equivalent computational models. The criterion for choosing between them, then, cannot be epistemological.

Possible criteria are utility and aesthetics, which are determined within a particular context of use.

Since connectionist and formalist models, on this account, are breeds of computational systems, the subsequent discussion on the nature of knowledge representation within the computational model can be taken to apply to both of them.

Benefits

The computational system has been a very useful model for studying cognition. It has had several advantages for cognitive scientists and computational psychologists. It has value on methodological grounds, since it demands theoretical clarity and can reveal if intuition has crept in without knocking (Johnson-Laird, 1988). Those researchers in the field who design their theories in the form of programs have an advantage, in that programs must be coherent and complete in order to run.

Some of these programs, such as those that model chess-playing, have enjoyed some success in their respective fields (e.g., Boden, 1987)[19]. As achievements multiply, however, two important issues arise.

First, animosity seems to grow as the achievements do[20]. Reactions to computation, to the interpretation of its success as a model of mental processes, are often visceral. According to Bronowski (1971),

> This is where the fulcrum of our fears lies: that man as a species, and we as thinking men, will be shown to be no more than a machinery of atoms. (p.7)

Dennett (1996) has gone to great and persuasive lengths to show how misguided these fears are. He argues that underlying the seemingly nonalgorithmic processes of evolution and mind are basic, plodding algorithms. In other words, at the root of meaning is nonmeaning. The intuition that at bottom, our minds do *not* reduce to a series of mindless, mechanical rules, is simply wrong[21]. Nonetheless, the idea of cognition as computation, as a rule-based symbol system, continues to make many people unhappy. Unhappiness, however, is not a good reason to abandon a research programme (see footnote number 20).

The second issue is related to the interpretation of computer achievements. Behind the success, what exactly is being modelled? To what extent might attributions of 'understanding', 'meaning' or 'interpretation' be inappropriate in the computational context? This is a crucial question in terms of a computer program's capacity to represent knowledge. We will return to it very shortly.

Drawbacks

No single model can be complete. It can be more or less useful depending on how it advances a research programme, generating new interpretations and predictions, maybe suggesting solutions to some important problems, but no model of so complex a phenomenon as the mind can account for every interesting facet or feature.

This is *not* a weakness specific to the computational model. It is true of all metaphors. We must distinguish between 'using' and 'being used by' a metaphor (Turbayne, 1971). When used without awareness, the screen of a metaphor becomes a mask.

> The victim of metaphor accepts one way of sorting or bundling or allocating the facts as the only way to sort, bundle, or allocate them. (p.27)

We have to avoid conflating a model with what is being modelled. These concerns do not detract from the utility of the computational model. It just means we must explore what its limits might be. In the context of this thesis, I'm interested in looking at possible limits with respect to knowledge representation and meaning.

The Eliza effect

Remember the Wittgenstein account of meaning in terms of a set of interpretations determined within the contexts of use by members of a linguistic community? In what sense is meaning possible within a computational system? This question has received considerable attention, as cognitive scientists grapple with notions of 'meaning', 'interpretation', 'representation', and other related concepts. It is difficult to work with these ideas without being misled by intuition, especially when we are looking at computer programs in action.

ELIZA is a program written by Joseph Weizenbaum in the mid 1960s (Hofstadter and the Fluid Analogies Research Group, 1995). The program was designed to play (emulate) the part of a Rogerian psychotherapist, carrying on conversations via teletype[22].

If you just read the dialogue in the endnote, you may find it an impressive example of ELIZA's conversational prowess. In fact, much of the program's success is due to its role as a Rogerian therapist, since the 'therapist' is supposed to follow the flow of the conversation, drawing out and reflecting thoughts and emotions from the patient, without offering any of its own (Boden, 1987).

Further, the interaction is only successful when the patient gives credence to ELIZA's role as a therapist. The person must interpret the questions of the machine within the context of a Rogerian dialogue, and it is this interpretation that makes sense of ELIZA's words.

If the patient moves outside this context (i.e., into an alternative context of use), then the conversation can fall apart quite quickly.

> If ELIZA's human partner withdraws this assumption [that what is required is an exploration of her own feelings] (or, more generally, deviates from the psychotherapeutic role), ELIZA's responses rapidly deteriorate into eccentricity or outright nonsense. (Boden, 1987, p.108)

Computers can appear more competent, more capable of meaning and understanding, than they actually are. This has become known, thanks to Weizenbaum's program, as the

Eliza effect. It becomes clear, after many different interactions with the program, that ELIZA works the words only. She cannot tolerate a shift in context. Her apparent understanding then seems due to manipulation of symbols alone. Is there any sense in which we can suppose that semantics can enter into this manipulation?

Meaning, in computational terms

Boden (1988) argues that there is a limited sense in which meaning can be attributed to a formal syntactic system. The claim that computer programs are pure syntax rests on a misapprehension of the nature of representation in computational systems. A representation is not simply a structure, a declarative statement; it should also be understood in procedural terms: "Indeed, one might even say that a representation *is* an activity rather than a structure." (Boden, 1988, p.247).

The representation of knowledge is a very complicated issue. It's about as self-reflexive an activity you can find. Boden (1987) does argue quite succinctly, however, that knowledge can be organized as facts or as methods. There is no absolute distinction between 'knowing that' and 'knowing how'. The same information can be represented either way. For example, she explains that a recipe is usually represented in two ways: declaratively (the list of ingredients) and procedurally (the set of ordered instructions). Further, each can be converted into the other (p.381).

A computer program is not only a repository of information about the world, but also a set of instructions for acting on that information. When the program is run, it does things; it's *active*. It executes a series of procedures on the basis of its cache of information.

> The inherent procedural consequences of any computer program give it a toehold in semantics, where the semantics in question is not denotational, but causal. (Boden, 1988, p.250)

In other words, a representation is more than a syntactic pattern stored in the machine. Meaning of representations is generated by establishing causal links with other representations, both internal and external to the system itself[23]. This rings a bell. Recall that Boyd (1993) was concerned with the accommodation of theory to causal structure. Meaning was associated with causal relations among different elements, rather than defining sets of necessary and sufficient conditions (see pages 15-16).

Here then is an interesting commonality. The computational account of meaning offered by Boden (1988) mirrors, in its emphasis on causal relations, Boyd's causal theory of meaning, related to theory-constitutive metaphors.

The fact that a machine is capable of some understanding, of a certain amount of interpretation, says nothing about its (eventual) capacity to appreciate meaning in as full a sense as human beings. So far they don't, and it's unclear to what extent they might in the future. The point made by cognitive scientists is that the limited causal meaning that a machine can manifest may be one element or aspect of meaning in human terms (Boden, 1988).

So representations can be meaningful, to a certain degree. There remains a serious problem, however, with the nature of the representations that tend to be used in the machines.

For example, Johnson-Laird (1988) devotes the eighteenth chapter of his book, an introduction to the theory of computability, to a discussion of meaning within a symbol-manipulating system. According to Johnson-Laird, meaning depends on the creation of mental representations, or models, within the system. These models reflect the relation between words, or symbols, and things in the world.

In the interest of parsimony[24], however, the system will create only one model at a time. This model may be adapted later, based on new information, but it remains the unique representation of a state of affairs (which may be abstract as well as perceptible). The model is then used to determine the truth of statements about the world. In other words, Johnson-Laird is relying on the (unfounded) intuition that there is a single best representation of a particular 'state of affairs', and conceptual progress consists of revisions to the model.

Hofstadter *et al.* take issue with this common view, and they take it one step further. They describe the efforts of cognitive scientists to design computational models of analogical thought. The standard methodology highlights a serious limitation in the common conception of representations, and their relation to high-level perception. Most analogy-makers, and most artificial systems in general, are designed with representations *already built in*. They are added to the system as *a priori* elements, rather than created by the system itself.

> Usually, researchers use their prior knowledge of the nature of the problem to hand-code a representation of the data into a near-optimal form. Only after all this hand-coding is completed is the representation allowed to be manipulated by the machine. (p.173)

This is a major drawback, since it means that the computational systems so designed could never capture the flexibility of human thought. When no account is taken of the processes of representation-formation, the resultant account of cognition is necessarily limited, because the actions of the computer are based on a single best representation, as encoded by the programmer. Much effort is devoted to designing computers to *resolve* ambiguous input, while little value is placed on the *generation* or *manipulation* of multiple, or ambiguous, outputs.

In sum, the computational model has enjoyed considerable success in the realm of cognitive science. It is however limited, as any model must be. It does have several weaknesses with respect to knowledge representation. The link between syntax and semantics is tenuous, and the attribution of meaning to computational processes may more often be due to the Eliza effect than to any substantial understanding on the part of the machine. If meaning is a function of contexts of use, then the inability of ELIZA, for example, to deviate from the role of Rogerian therapist may be an indication that the computational model is not a complete account of meaning.

The fact that computer programs are commonly supplied a single best representation of a piece of information, whether in declarative or procedural form, is currently a serious weakness of the computational model. Hofstadter *et al.* suggest this weakness could be remedied by creating a stronger bridge between the perceptual and cognitive processes within the computer. This has been an infrequent approach, they argue, because the majority of cognitive scientists do not appreciate the critical importance of the relation between cognition and perception, espousing instead the view (long abandoned by philosophers) of knowledge, through language, as an objective reflection of the world as it is.

Whether this limitation can be remedied in practice is unclear[25]. The point is that, at this moment, there are no computer programs that can model the ability required to produce and contend with multiple representations. The first part of this thesis looked at the importance of these issues in general. The next chapter is devoted to its importance in the context of education.

Chapter 5 Multiple representations in theories of instruction

> With the wisdom of hindsight we can see how the advent of the digital computer triggered a "fashion industry" in new ways to think about the mind and how to build learning machines. (Pagels, p.117)

The computer metaphor has had considerable impact on cognitive theories of instruction. In a chapter describing the relation between cognition and learning, for example, Driscoll (1994) devotes 36 pages to the information-processing model of cognition and just over 2 pages to alternative metaphors within the same basic paradigm. At the end of the chapter, there are 2 pages (in other words, about 5% of the chapter) about the rhizome metaphor, a model of the mind that truly falls outside the family of computational models. The weight of this text, in sheer numbers of pages, is clearly on the fundamental computational model.

Driscoll describes such models in general terms of information flow through sensory, short-term and long-term memories. As this information flows, it is being processed, transformed into representations subsequently stored in the mind for variable periods of time (see also Smith & Ragan, 1993).

In the descriptions of the computational model, no account is given of multiple representations of information in the mind. It is assumed that information is only encoded in a single representation. Peppered throughout examples of information flow are references to 'a' or 'the' representation. Mention is made of 'alternate' representations, but Driscoll is here referring to the presentation of information in different forms, rather than from different perspectives. An altern*ate* representation is an elaboration of the primary information (as a graph might help the learner encode verbal information), but it does not provide the learner with an alternat*ive* perspective.

Computational models have tended to ignore our capacity for multiple representations, and so have the information processing theories based on these models. Any theory of instruction based on the computational model will necessarily be limited in this respect.

So what?

Whether this limitation is important depends on the importance of multiple representations to instruction. I will argue there are contexts in which multiple representations ought to be active in the minds of learners. There are times when a learner should *not* be taught or expected to form a single representation of a phenomenon, and in these cases the computational system is not a good model of an important aspect of cognition. There is a criterion for whether single or multiple representations are required. We return once again to the concepts of meaning and truth.

Meaningful truth, true meaning

Here is another approach to meaning and truth, one that is compatible with the Wittgensteinian account. Arendt (1971/1978), standing on Kant's shoulders, draws a clear distinction between truth and meaning. She argues that they are related as the intellect is to reason, or as knowing is to thinking.

To know is to decide what is true and what is false, to identify a state of affairs as it is. The quest for truth, the goal of the scientist, ultimately depends on sense perceptions and common sense[26].

To think, however, has nothing to do with attributions of truth.

> *Knowing* certainly aims at truth, even if this truth, as in the sciences, is never an abiding truth but a provisional verity...*Thinking* can and must be employed in the attempt to know, but in the exercise of this function it is never itself; it is but the handmaiden of an altogether different enterprise. (Arendt, p.61; italics added)

The goal of thinking is meaning, rather than truth. The object of thinking is not to identify *what is*, but "*what it means for it to be*" (p.57; italics in original). Meaning and truth are orthogonal; they are not mutually exclusive, but neither is one dependent on the other. For example, something can be both meaningful and false, as are the medieval proofs of the existence of God (p.61). A statement may also be true but meaningless, it is 'hokum', "words without meaning, verbal filler, artificial apples of knowledge" (Barzun, 1959, p.25). Barzun argues that it's better to give the wrong answer than to blindly parrot an answer you don't understand.

There are some concepts of which we test truth, and others of which we must determine meaning. The latter are unknowable; these are the questions that cannot be resolved but that we are driven to think about (such as the existence of God, and maybe even the nature of the self).

A corny example: compare the truth of your life to its meaning.

Multiple meanings

How are these two goals of human cognition, truth and meaning, related to the idea of multiple representations?

Representations are forms of information. They are created to reflect (structurally, functionally, or in some other way) the way we perceive and think about what surrounds us.

There will be times when you accept that the world is structured in a certain way, accessible to the senses, and at these times you will pursue truth. You will seek the single best way to represent things in the world, and reject other possibilities as misrepresentations, or falsehoods.

At other times it will be better to believe there is no single best interpretation of a phenomenon. You will then search for its meaning. There is no criterion by which to determine the truth of different representations, but some will be more right than others, judged by a criterion of aesthetics, perhaps, or of utility. It may be that one representation appears false from the standpoint of another.

Truth requires single representations. It's about finding the single best answer to a question. Meaning, however, requires multiple representations. You have to look at different possible answers in different contexts of use. In this way you learn more about the question.

Where does the meaning lie? The meaning of an object, for example, is what stands behind its various appearances (Arendt). It cannot be known. As we saw in the first chapter, we cannot know what underlies our perceptions, but something does, and that something is the goal of thought.

The quest for truth is immensely valuable; it is as much a part of the thinking self as the quest for meaning. In the case of instruction, the ultimate goal, of truth or of meaning, must depend on the context.

Instructional contexts

When you want students to learn something 'true'[27], and about truth, then you can encourage the creation of single representations of pieces of information.

However, if your goal is to teach something meaningful, and so teach also about meaning, then you must encourage the learners to create and grapple with multiple representations.

Imagine spending three months with twenty students. Do you want them to walk away with a piece of truth or meaning? In fact, I shouldn't ask the question so baldly. The choice will depend of course on the perspective you have adopted. The first triad of chapters should alert you that there can be no definitive answer to this question. It cannot be otherwise. The important thing is to raise the question and look at alternative solutions. The following discussion is based on my perspective, and is meant only to broaden and not to resolve the issue.

It seems to me that the distinction between meaning and truth, as instructional goals, can be matched, though not neatly, with the distinction between education and training[28]. Instead of giving definitions for each, I will offer prototypical examples, in the Wittgensteinian tradition.

First, an example of training:

The learners are employees in the information department of a job creation centre. They are responsible for answering questions, over the phone or in person, about the programmes offered by the centre.

An example of education:

The learners are twenty-six students in a history class. They are currently studying nineteenth-century relations between Canada and the United States.

What are the learning goals in these two situations?

The employees are being trained in information retrieval skills, so they may respond to questions quickly and accurately. They are expected to identify the best answer to a client's question, as quickly as possible. In a sense, then, the employees should be trained to search for truth so they may provide the client with the best possible answer.

What learning goal is appropriate for the history students? Should the students leave the course with a definitive account of Canada-US relations in the past, a single best story about what happened? If so, the teacher can project a unique version of events, thereby obscuring other possible versions, or representations. The students will leave the class armed with the truth.

Or the students could work towards the meaning behind appearances by adopting several different perspectives. They must think critically and study many different sources, each based on a different perspective: Canadian, American, military, journalist, commercial, agrarian, young, old, male, female, native, immigrant, et cetera.

What will they uncover? Analyses made from different perspectives, based on different representations of events, may reveal something of the meaning behind the perspectives. In the end, you can never uncover the full meaning of an object, an event, or a thought. We must learn to accept that ambiguity, rather than assume it must be resolved. We identify our humanity in dilemmas, not in resolutions (Bronowski, 1971).

> The relationship between teacher and student, if it is to be *productive*, necessarily resists the importation of techniques with the primary function of abolishing doubt and insecurity...Perplexity is part of the package. (Solway, 1997, p.49)

The value of searching for meaning is the journey itself, the means you use to search. It does not admit of resolution.

The quest for meaning

Solway (1989 & 1997) describes education as a continual process, a never-ending journey to fashion the self.

> [E]ducation...must be understood either as a partial *anamnesis* in the sense of recalling an innate proclivity for disinterested curiosity into being--provided that it exists; or as a *metanoia*, the upward metamorphosis, the reorientation of sensibility in which the governing perspective on existence, that amalgam of assumptions and convictions about the world we are in the habit of calling "personality", is radically changed, intensified, and expanded. (pp. 94-95)

The goal of education, using the quest for meaning as a means, is the transformation of the self. The learner must "change, intensify, and expand" her perspectives, I would argue, by creating new and radical representations, straining toward meaning and so strengthening her own identity and sense of self. It is a painful process, and it never ends.

Solway (1989) likens education to drama. The transformation is facilitated by the teacher, who guides the student through processes that proselytise through dramatic ritual, leading to spiritual development, the creation of a new personality. Only through changing and strengthening the personality can the learner cope with despair, and rise in wonder.

It is the relationship between teacher and learner that is critical. The teacher must have the requisite personality to effect change in the student, projecting not only herself but also the discipline, its authorities and perspectives. The student, in turn, assumes equal responsibility for the process by working to identify and embody an emergent sense of identity.

> The class is then a learning site in which the faltering but questing subjectivity of the student comes to a progressively more adequate concept of itself, or in which the student recognizes that *his or her identity is a function of continuous learning.* (Solway, 1997, p.125)

Education and training

Solway (1989) argues that the simple acquisition of skills is what characterizes training, while the transformation of the self is the true object of education. My two prototypical examples are clearly simplistic, but serve to make the point.

The centre employees will be trained to answer questions correctly and quickly. The employer often does not have the resources to do more. There is no question of self-development, or transformation of identity. Some stalwart learners may choose to seek out meaning on their own, but the process may be next to impossible without facilitation from a teacher, or guide[29].

The second example may ideally be considered a good occasion for eliciting a search for meaning from the students. In practice, it may not always be possible to accomplish more than the skill or concept acquisition of the first example. But in this case, there is certainly potential for more. In fact, it is the responsibility of the educator to provide more, to stimulate the student to grow, to transform her personality and to forge a new sense of identity.

Self-knowledge comes from learning to ask questions and facing fundamental human dilemmas (Bronowski, 1971). The system remains open. We shouldn't be taught to expect resolution. This is where the computational model can lead us astray. It is not designed to cope with ambiguity. There remains the important step of creating new models, new theoretical frameworks that can persuasively represent the importance of multiple representations to the mind and to education.

The danger is in allowing the computational model to become an epiphor (see pages 18-20), a model accepted without challenge. We need to forge new diaphors of the mind, metaphors that can account for the necessity of adopting multiple representations in a search for meaning.

Chapter 6 Constructivist allies?

What is the relation between constructivism and the ideas discussed so far? Driscoll offers an account of some of the assumptions underlying constructivist theories. In essence, constructivists argue that there is no correspondence between the world and our knowledge of it. A constructivist may then take one of two positions. She may take a radical stance, and assume that any interpretation of reality is as good as any other. Von Glasersfeld is a noted proponent of this relativist view (Matthews, 1994). Alternatively, she can take a milder stance, in the belief that knowledge is subject to certain constraints, whether biological or social.

Each of these stances, whether of radical constructivism, mild constructivism, or my own, acknowledges the determination of meaning through multiple interpretations. Radical constructivists must give meaning a very broad scope; they have no criteria for the evaluation of different perspectives. A phenomenon can be interpreted, or given meaning, in innumerable ways. Having asserted that we cannot know the world as it is, radical constructivists take the next step and argue that there *is* no world to be known. That is, there is no reality independent of our experiences.

Mild constructivists, on the other hand, do propose criteria for selecting certain interpretations over others. They argue that "[t]here must be limits to what sense learners make of their environment and their experience" (Driscoll, p.361). The question is, what is the impact of the environment on these limits? Clearly, from what I have argued thus far, my position has little in common with radical constructivism. I have consistently asserted that there is a world independent of our experiences, and that there are certain criteria (understand limits) by which we determine which interpretations are more right than others. My position does seem rather like that of the mild constructivists, but only to the extent that phenomena in the world help determine the limits of interpretation. Social negotiation and critical engagement based on experiences in the world both play roles in the assessment of different interpretations. Perspectives are compared within a particular context, and some will fare better than others. I agree with mild constructivists who use experiences with objects and events, to the extent they are knowable, as criteria for evaluating multiple perspectives. There is some correspondence between the world and what we know of it, as Ortega y Gasset and Arendt argue. I think this makes the negotiation of meanings more than a question of social convention.

Conclusions

One significant limitation of the computational model is that, at the present time, it cannot account for the creation and evaluation of multiple perspectives. I have argued, at length, that these multiple perspectives are the means to the best possible understandings of a phenomenon. Each interpretation is like the light refracted off each side of a diamond, or each plane of a kaleidoscope. Each one provides a distinct insight; no single one comprises the whole.

I approached the idea of meaning in several ways. The sense of meaning arising from a shared context of use is based on the work of Wittgenstein. A second perspective, contrasting truth and meaning, was borrowed from Arendt. Both are aspects of meaning understood in terms of several 'right' interpretations, whether complementary or contrasting. Our understanding of the mind was used as an example. Through models, we construct different versions of a phenomenon. The 'right' versions are based on shared cultural commitments as well as correspondences between subject and object, or the 'knower' and the 'known'. I call for alternative 'right' interpretations of the mind, to supplement the perspective offered by the computational model.

One of the most important goals of education is to foster this approach to meaning, and to encourage the manipulation of multiple understandings of any phenomenon. There are at least three requisite skills: (1) the ability to create many interpretations, (2) the ability to select the 'right' ones, and (3) the ability to maintain these interpretations without trying to resolve the resultant ambiguity.

At long last, a fable[30]

There was once a very tall white tower that reached up further than anyone could see. The top was always hidden in clouds. People came from all over to study this tower, because they suspected there was something important up there, something they should know about.

Many rumours fed the small town that grew up around the base of the tower. The story that spread most widely was that at the very top of this tower there was a small room, and in the room lived a toddler-prince. No one knew quite how to describe him, but each person who told the story carried in her head an idea about what a toddler-prince might be like.

People set out to study the tower itself, some measuring circumference and diameter, others working to identify its colour from a set of white swatches, so the colour could be named. But there are so many different whites, and then the colour itself would change over the course of a day: a yellowish glow in bright sunlight, a softer grey white at dusk.

One fellow clambered up a very tall tree that grew alongside the tower. He peered up with his binoculars, on a day when there were fewer clouds, and thought he saw a tiny window.

"At long last!" he cried. "I see the toddler-prince!" He described the shadows cast against the window in minute detail, and he claimed the prince was a giant, seven feet tall.

Another intrepid group scaled the wall of the tower. The tower was so very tall that they could not reach the top, but one woman managed to clamber a little higher than the rest. She pressed her ear against the wall, and she heard some scratching noises. She held a tape recorder up tight against the wall to record the sounds. As soon as she returned to the foot of the tower, she turned the volume full-blast, and played the noises for the crowd.

"At long last!" they cried. "We hear the toddler-prince! But what do these sounds mean?"

An analysis was done on the sounds, and the data showed that the toddler-prince was as tiny as a blue-winged warbler. This made sense to many people, since a blue-winged warbler has a beautiful yellow belly and head that would match the colour of the tower on a very sunny day.

The debates and experiments continued for years. Reputations were made, and blown. No one ever did confirm what the toddler-prince was like, or even that it really was a toddler-prince who lived in a room at the top of the tower. The ones who learned most were the children who drank up all the latest ideas, without being asked to choose among them.

Endnotes

[1] The question is, are these truly different trees each time I look from a new angle, or just different ways of looking at the same tree? It may be argued that different perspectives do not necessarily create new objects. In this thesis, however, I take the more extreme position, asserting that novel representations do give rise to new meanings.

[2] Then, just when you might think our desire for classification is (pathologically) systematic, our language takes an idiosyncratic turn. How is a gaggle of geese different from a pride of lions? Apple orchards from orange groves?

[3] Here I have let show my cultural bias. A robin may be considered 'the' bird in my cultural context, living in a city just within the southern cusp of Canada. People raised within different traditions, in other parts of the world, may identify a very different prototypical instance than I do.

[4] Much of the following discussion treats of metaphor in metaphorical terms. Though this approach seems circular, it is a common feature of accounts offered of metaphor, whether the author explicitly recognizes the fact, as do Black (1962) and Goodman (1988), for example, or not. This makes sense since, as we shall see later, theory is rooted in metaphor. Therefore, no theoretical account of metaphor can be developed independently of metaphor.

[5] I use this metaphor to illustrate Black's concepts of primary and secondary subjects and of the interaction between their respective implication-complexes. By choosing a literary metaphor I do not mean to imply that literary metaphors are better or more interesting examples of metaphorical statements than scientific metaphors, or metaphors from any other discipline.

[6] Mac Cormac claims a statement is true insofar as it agrees with certain prototypical natural categories, through which we order things in the world. Based on the claims of the preceding chapter, instead of truth we can speak of 'rightness', in the sense intended by Putnam. Leary (1994) draws a similar distinction between a true story and a likely one.

[7] Boyd offers biological species as the classic instance of a homeostatic property cluster kind. Organisms tend to vary along a near-continuum of morphological and other characteristics. Species membership will depend on (and is usually defined in terms of) the possibility of interbreeding. Those organisms that can interbreed are members of the same species; those that cannot interbreed are not. Interbreeding acts as the mechanism by which organisms can be distinguished as separate species.

[8] Boyd believes there is an actual structure of the world to which we may eventually, through study, have access. I argued in the previous chapter that although this structure may exist, we cannot know it as it really is. This question of whether classes are real or nominal (based on definition rather than essential difference) is a complicated one. Although I may disagree with Boyd's position, his account of theory-constitutive metaphor remains very useful.

[9] What is the relation between metaphor and model? A model develops and pursues the implications of a metaphor: "Every metaphor is the tip of a submerged model." (Black, 1993, p.30). A model is generated on the basis of a metaphorical insight. In this case, the basic insight that a DNA molecule has a helical structure led researchers to develop a highly refined double-helix model with very particular properties.

[10] The staircase model of a DNA molecule describes the way in which pairs of bases (adenosine and thymine, and guanine and cytosine) act as stairs held between strands of polynucleotide chains. Although the double helix model has been adopted with much experimental success by biochemists, there are other proposed structures. One example is the Z-form of DNA, although it is described as a peer rather than a successor to the standard model (Purves and Orians, pp. 301-305).

[11] In her master's thesis, Ovenden explores several different representations of the world as seen through maps, an international art exhibit ("Magiciens de la Terre") and the images projected by a clothing manufacturer (Benetton's advertisements as well as its magazine *Colors: A Magazine About the Rest of the World*). She identifies the role of each representation "in mediating our experience of the world by defining and positioning it in different ways, each with its own agenda, each with its own determined set of meanings" (p.5). For my purposes, however, I chose only to focus on the first of the representations explored by Ovenden: the world as seen through an atlas.

[12] South America has an area of 6,9 million square miles, while the area of Europe is just 3,8 million square miles. Another example: Alaska and Brazil appear to be about the same size on the Mercator map, but Brazil is about five times bigger than Alaska (Peters, 1989).

[13] Linear perspective presupposes a vanishing point, the apex of the visual pyramid. That is the point at which all the angles in a painting, for example, converge. From the vanishing point, the visual rays extend out to the flat surface of the painting (which is the planar cross section) and onto the surface of the eye, creating the illusion of three-dimensional depth on a plane.

[14] Boden (1987, p.166) gives a funny example of the vagaries of translation, in the context of describing language translation programs. If you rely on dictionary definitions alone, the following sentence, if translated from English to Russian and back to English, would morph from "The spirit is willing but the flesh is weak" to "The whisky is fine, but the steak's not so good".

[15] This point (that knowledge can be represented through both structure and process) will be postponed until a later discussion about representation and meaning in computational systems.

[16] In real connectionist machines, the connections are hardwired, but the connections can also be simulated, to an extent, on von Neumann machines.

[17] Boden (1988) later suggests that the term 'paradigm' may be misleading in the case of computational psychology, since it implies that the majority of practitioners accept this model. In fact, this sociological criterion does not yet seem to be met.

[18] Boden actually discusses *three* types of knowledge: explicit, implicit and tacit, crediting this distinction to Daniel Dennett. However, I think the contrast between explicit and implicit is sufficient to make the point.

[19] But what abilities are involved in playing chess, and are these skills that tap deeply into our conception of the mind?

> Lord Suffolk had said you can have a brilliant chess player at seventeen, even thirteen, who might beat a grand master. But you can never have a brilliant bridge player at that age. Bridge depends on character. Your character and the character of your opponents. (Ondaatje, 1992, p.192)

[20] Here is one way to deal with this concern. If a computational model were to successfully emulate human output given similar input, then it may be equivalent to a theory of the mind. Remember, however, that equivalent models do not necessarily imply the same means. Even if a computer simulated human thought, it could do so in a different way. Human thought processes may or may not be algorithmic. A 'successful' computational model would not resolve this question.

[21] Consider this quote from Dennett:

> Those who think the human mind is nonalgorithmic should consider the hubris presupposed by that conviction. If Darwin's dangerous idea is right, an algorithmic process is powerful enough to design a nightingale and a tree. Should it be that much harder for an algorithmic process to write an ode to a nightingale or a poem as lovely as a tree? (p.451)

If thought processes turn out to be algorithmic, however, this discovery may not justify the design and development of computational models to represent the mind. Minds have been evolving for millennia. On top of that, each individual mind lives through its own particular set of experiences. To argue that the mind operates according to computational processes does not necessarily mean we can construct a computational model that does justice to the mind, and especially to individual minds.

[22] Here is an example of a dialogue between ELIZA (in caps) and a human being (Boden, 1987, pp. 106-107):

Men are all alike.
IN WHAT WAY
They're always bugging us about something or other.
CAN YOU THINK OF A SPECIFIC EXAMPLE
Well, my boyfriend made me come here.
YOUR BOYFRIEND MADE YOU COME HERE
He says I'm depressed much of the time.
I AM SORRY TO HEAR THAT YOU ARE DEPRESSED
It's true. I am unhappy.
DO YOU THINK THAT COMING HERE WILL HELP YOU NOT TO BE UNHAPPY
I need help, that much seems certain.
WHAT WOULD IT MEAN TO YOU IF YOU GOT SOME HELP
Perhaps I could learn to get along with my mother.
TELL ME MORE ABOUT YOUR FAMILY
My mother takes care of me.
WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU
My father.
YOUR FATHER
You are like my father in some ways.
WHAT RESEMBLANCE DO YOU SEE
You are not very aggressive but I think you don't want me to notice that.
WHAT MAKES YOU THINK I AM NOT VERY AGGRESSIVE
You don't argue with me.
WHY DO YOU THINK I DON'T ARGUE WITH YOU
You are afraid of me.
DOES IT PLEASE YOU TO THINK I AM AFRAID OF YOU
My father is afraid of everybody.
WHAT ELSE COMES TO MIND WHEN YOU THINK OF YOUR FATHER
Bullies.
DOES THAT HAVE ANYTHING TO DO WITH THE FACT THAT YOUR BOYFRIEND MADE YOU COME HERE

[23] The question of the relation between representations in the mind and out in the world is fascinating, but outside the scope of this thesis. Two authors, with computational models of the mind in tow (Edwin Hutchins, *Cognition in the Wild* and Ron McClamrock, *Existential Cognition*) explore this issue at great depth. Both conclude that the individual is not the appropriate unit of computational analysis, and that cognition should only be studied in the context of the environment.

[24] Johnson-Laird argues that one model is sufficient since an infinity would be too many: "An infinity of possible worlds, as the linguist Barbara Partee has observed, is too big to fit inside anyone's head." (p.338) But why assume one must choose between one and infinity? There may be an infinite number of *possible* representations, but as Putnam said, some will be more 'right' than others. Johnson-Laird gives no reason to suppose we should adopt one representation over several 'right' ones.

[25] Hofstadter and his team are investigating this problem, and they mention several other researchers working in the same area. Apparently, most of the work is being done in microdomains, which suggests to me, that even if it's possible to solve this problem in practice (to design computer programs that can generate and work with multiple representations), that day is a long way off.

[26] Arendt refers to common sense as the "sense of realness" (p.50-51) because it can confirm that perceptions created by each of the five senses all reflect different aspects of the same object. Further, it is common sense that makes the objects of the five private senses public; in other words, it is through the sixth sense that we pick out an object (corresponding to information from the various senses) in the world, though it may appear differently to each of us.

[27] Here again I mean true such as it is perceived to be, in a specific context.

[28] I have used the terms 'education' and 'training' in a particular way. I later define them by means of prototypical examples, but to avoid any unnecessary confusion due to how they are defined in other places (e.g., Smith and Ragan, 1993), these are the general senses in which I mean these terms: education as development of the mind and the self, and training as the inculcation of specific skills and concepts.

[29] This is why I don't like the idea of professors as remedial tutors. All students need to be pushed and encouraged to reach beyond their grasp. I think this is a crucial role for the teacher to play. It's not enough to hand out library memberships to students who seem to achieve well on their own. Isn't education a community event?

[30] Solway (1997), in a chapter titled "The Anecdotal Function", argues that narrative is painfully lacking in educational discourse.

> ...[narrative] enables us both to structure the inchoate plasma of drives and impulses of which we presumably consist and to innervate the impersonal and subjectless world of theoretical discourse. (p.247)

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