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CHAPTER 10

THE NATURE OF STUDENT LEARNING AND KNOWING IN SCIENCE

As outlined in previous chapters, the representation construction approach is underpinned by sociocultural, pragmatist, semiotic perspectives on learning and knowing. In this chapter we will:

- review how each of these perspectives relate to this pedagogy, illustrating with the animals in the school-ground classroom sequence,
- explore how this classroom practice relates to practice in science itself
- discuss how the pedagogy promotes understandings of the nature of science, and
- clarify the nature of quality learning, and knowledge, from this perspective.

LEARNING AS PARTICIPATING IN AND ENGAGING WITH PRACTICE

The fundamental point of departure for sociocultural perspectives is that learning in science is envisaged in terms of increasingly expert participation in the discursive practices of science. These include the way representations are generated, negotiated and justified within the scientific community and subjected to rigorous scrutiny through agreed evidential processes. At one level the approach could be seen as an effective way of addressing the recognized problem of supporting students' acquisition of key science concepts, through promoting a more active and student centered approach to learning, and that is the initial perspective of teachers we have worked with in developing and disseminating the pedagogy. However, the participatory metaphor is much more congenial to our work than the acquisition metaphor (Sfard 1998) in that it better captures the way representations are generated and used to solve problems, as tools capable of negotiation and refinement, rather than as ideas that have a settled and agreed provenance. We will return to this notion of conceptual change, and concepts, later in the chapter.

Allied with this perspective is that of the classroom as a 'community of practice' which acts as a site for knowledge generation and negotiation, in a process of co-construction whereby teachers and students together hold up ideas for scrutiny and refinement, in pursuit of a shared need or problem. The emphasis is different

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from traditional cognitive 'acquisition' perspectives on two counts – first, in terms of the control of knowledge, which is recognized as jointly generated, with students having some agency in the process of establishing a need, and generating, critiquing and refining representations in a public process. Second, the end product is viewed differently, being seen in terms of competent action within this community, rather than declarative knowledge in a person's head.

The pragmatist perspective emphasizes that meaning-making and problem-solving in science occur when the cut and thrust of language (broadly conceived of as dialogue, debate and logical proof) and the manipulation of other representational tools are used to engage with situated challenges (Wittgenstein 1972), rather than view science learning as the acquisition of stable conceptual structures with appropriate interconnections, as in conceptual change accounts. This view is exemplified by the Peircian triad of meaning making, with representation and referent tightly interconnected in a hermeneutic process of meaning making. The recognition of the multi-modality of the representations used in science to generate knowledge, and in classrooms to support student learning, constitutes the semiotic turn in this perspective.

Key concepts in this account of learning are those of mediation, and artefact. From a Vygotskian perspective, learning is inevitably a meditational process where language, and representations and artefacts more generally, are the means by which learners are supported to develop new practices implying new ways of looking at the world. Thus, language forms, such as technical terms, analogies and metaphors, multi modal forms such as diagrams and animations, role-plays, and models, or physical tools and equipment, are the means through which students are inducted into more expert practice in a field. These language forms – words, or diagrams and other visual forms – are constitutive rather than illustrative of ideas. In these discussions we are taking the terms 'representation' and 'artefact' as being broadly synonymous, but they tend to be used in different theoretical traditions, with different emphases. Artefacts, in the distributed cognition literature for instance, are man-made objects constructed to improve cognition (Hutchins 1995). They can be tools and symbols, including verbal language, and even abstracted ideas and processes (Tytler et al. 2012) as well as tools that are not necessarily conceived of as being in relation to objects or conceptual ideas. A representation, on the other hand, is thought of as standing in for something else, and in Peircian terms has an intimate relationship with a referent and the meaning attached to this. In practice, however, it could be argued that the terms occupy the same territory, within a given theory.

These ideas have been used to justify the construction of representations that is central to the pedagogy, a departure from the more common concern with supporting students to interpret the canonical representations of science, to achieve conceptual clarity and accuracy. We will further explore this notion of representation construction in a discussion of quality learning, later in the chapter.

There are many instances illustrated in the preceding chapters in which the role of representations in mediating learning has been explored. The coordination of representations / artefacts such as drawings, role-plays and 3D models as part of the discursive tradition around particle ideas, was described in chapter 5 and linked to notions of affordances of the different modalities, and to the epistemic practices of science more generally. Support for this perspective on learning science is given in the case study of the Year 5/6 Animals in the school-ground unit of work, parts of which have appeared in earlier chapters.

Mediation and Representation / Artefact

The mediating role of artefacts / representations is often thought about in terms of activity theory, in particular with Engestrom's (1992) formulation in terms of activity theory triangles. Figure 10.1 shows a major activity triangle dealing with the mediating role of artefacts in the animals in the school-ground unit.

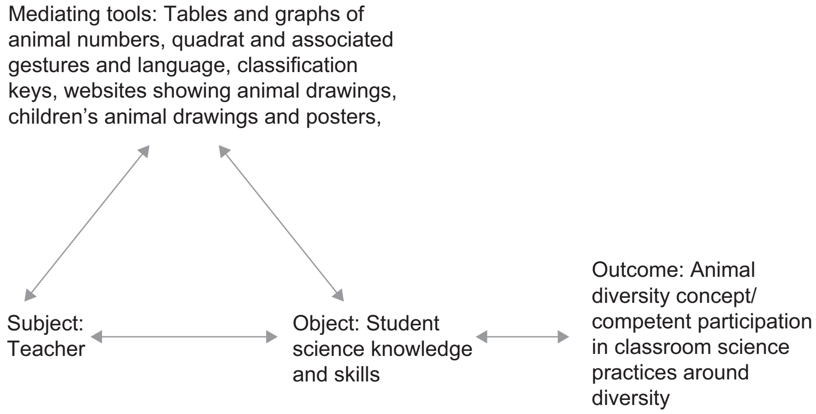

Figure 10.1. Engestrom's activity theory triangle showing the meditational role of representations and artefacts in establishing children's understandings/practice in relation to animal diversity.

A simplistic rendering of the notion of mediation represented by this diagram would have the mediating tools as being simply effective means to the end of establishing students' concept of animal diversity, thought of as declarative knowledge that somehow jumps clear of the means by which it was achieved, as though a difference could exist between the nature of a concept and how it is generated. A sociocultural perspective however would recognize that the outcome is intimately bound up with movement around the triangle, and that understanding is best thought of as an emergent practice involving communal negotiation and use of a variety of representations/ artefacts. The understanding involves competent participation in these discursive practices, and is itself emergent, unresolved, and situated in the activity. This also accounts for the necessary persistence of conceptual pluralism in all scientific research.

Engestrom's triangles are representations of a pedagogy built around the notion of mediation, with the teacher envisaged as driving an intentional process. The Peircian triad (Figure 10.2) is a more fundamental way of looking at the mediation process, linking representation with the referent phenomena in a circulating process of meaning making. The triangle does not speak directly to a pedagogy, but implies that the conditions for quality meaning generation involve the opportunity for constant circulation round the triangle, coordinating multiple, multi-modal representations linked to experience and evidence to build practice.

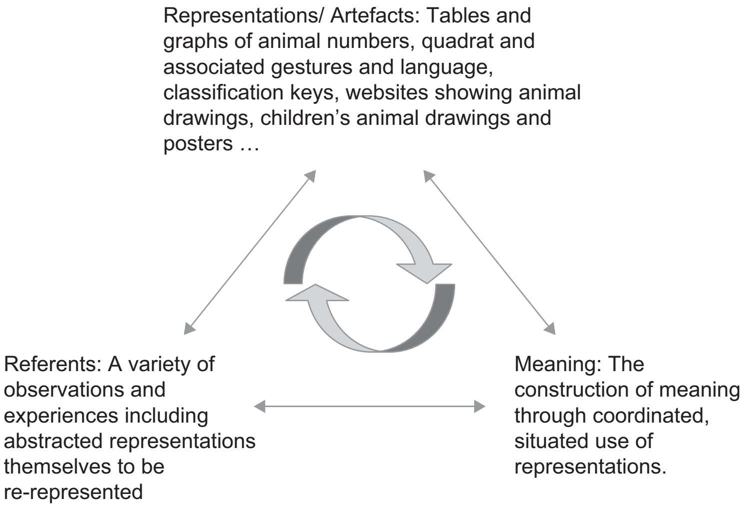

Figure 10.2. The Peircian triad showing the mediation role of representations in generating meaning in the area of animal diversity.

The triangle represents an idealisation of meaning-making in theory, but also implies the particular meaning-making practices of individuals entailed in the resolution of the links between representation, referent and meaning. In practice there will multiple and incomplete alignments for individual learners, and between individuals in groups of learners, as the situated meanings of individuals encounter slippage and inconsistency over time. However, we argue that this focus on representational coherence and adequacy entails a practical way to address this fundamental challenge of learning science.

It was argued in Chapter 5 that the key to the mediation function of representations is the way they channel and focus attention through their particular affordances. Each representation (and physical artefacts such as quadrats, other measuring tools, or digital microscopes) offers a selective view of an aspect of a phenomenon or process. The generation of meaning can be understood as the coordination of these multiple perspectives to solve a problem such as analysing a situation and communicating an explanation. Thus, deepening understanding can be viewed as increasingly agile and insightful performance of disciplinary discursive practice. These ideas will be explored, through student learning in the Year 5/6 unit: *Animals in the school ground*.

ANIMALS IN THE SCHOOL GROUND

This unit had two distinct parts; the first was an exploration of animal (invertebrate) diversity in school-ground habitats, the second was a study of animal movement (form and function) through model construction. The unit was described in broad terms in Chapter 6, to analyse the role of representation in reasoning. The sequence of events in the first part of the unit is described below.

1. Introduction to the school environment – identification of habitats to study. The overall questions for the unit are a) what animals are found in the school ground habitats? b) what characteristics do the animals have that enable them to survive? and c) how do the living things interact and depend on each other?
2. Students undertake a preliminary investigation of their habitat. They predict what they will find there. They spend time drawing and observing as much as they can. They report back.
3. The idea of scientifically studying a habitat is introduced, and the need to develop quantitative data through sampling, measurement and representation. Students were introduced through discussion to the idea of sampling distributions.
4. Students explore their habitat, counting animals and recording a range of environmental conditions. They take notes as a group with a view to developing a poster.
5. Direct teaching occurs concerning diversity and classification (broad animal groupings)
6. Students develop and display posters representing an account of their habitat, and present preliminary ideas about how the animals and plants interact.

In introducing students to the idea of animal diversity, and to habitat sampling, the teachers worked through a series of representational challenges, supported by introduction of a variety of mediating tools (representations/artefacts) through which the students came to explore and conceive of the diversity of animals in the environment.

Mediation Role of Representations

The sociocultural perspective, including the mediation role of representations, the operation of the Peircian triad, and the coordination of multi modal representations, can be seen in the sequence through:

- The discussion during the introductory class forum of a need to sample leading to the introduction of the quadrat, with gestures and words being used to establish

the idea of a sample space. The idea of counts of animals was expressed through suggestions of tallies, and graphs.
- The role of drawings and tables and graphs in focusing attention and supporting reasoning. This was discussed at some length in Chapter 6 where it was argued that these representations play an active role in shaping understanding of the distribution and variety of animals in the environment. Branching diagrams were used to represent animal classification, and formal naming systems were introduced, which were used by students in their internet searching to identify animals they found.
- The task of generating a poster focused attention on the need to coordinate representations of a variety of aspects of animals in the habitat.

Digital microscopes were used to study and photograph close up features of animal structure. These photographs were used to illustrate animal structures in the poster presentations. Short video sequences were used to study movement details.

The mediating role of multiple representations including sketches, physical models, role-plays, and talk in generating understandings of animal movement, was discussed at some length in Chapter 6. Each operates to confer further insight by virtue of the affordance (productive constraint) offered by the particular mode. Again, we argue that Jesse and Paul's understandings of centipede movement generated by this process, for instance, do not jump clear of these multiple representations to form some essentialised version of how the centipede moves. These representations, together with the practice of which they are a part, are continuous with / constitutive of the understanding that the boys generated of the animal's movement.

Epistemic Agenda and Community of Practice

A central perspective of the representation construction approach is conceptualizing classroom activity around the notion of practice that reflects the knowledge building practices of science. There has rightly been criticism of some characterization of investigative classroom activities as being 'authentic science', on the grounds that the purposes of school science are not the same as for science itself, the motivations of students are not that of scientists, the knowledge is not in the same sense 'new', and there is no equivalent person to the teacher, in science laboratories. Nevertheless, we would claim that pedagogies in science classrooms can to a very different extent represent legitimate practice and that an important aim of any science classroom purporting to focus on introducing students to the way science is practiced in real settings, needs to pay attention to understandings of its epistemic processes.

To this end we draw on the work of scholars such as Latour (1999) or Nersessian (2008) who have studied the generation of knowledge in science laboratories, emphasizing the communal generation of representations / models as central to the knowledge building process and the development of languages and artefacts that are deeply contingent and situated in their work to solve contextual problems. In their and others' work (e.g. Clement & Rea-Ramirez 2008; Gooding, 2004, 2006) a central process of scientific knowledge generation is model building. A further characteristic of scientific knowledge building is the process of alignment of ideas with evidence, and the small and large scale patterns of reasoning and argumentation by which knowledge is legitimated through rigorous scrutiny. We argued in Chapter 6 that the process of argumentation in science classrooms, if it is to adequately represent epistemic practices in science, needs to be situated in explorations based on genuine and agreed questions, that are subject to situated contingencies similar to those that occur in science, and that involve public processes of challenge and negotiation.

The aspects of the representation construction pedagogy conforming to these views of science epistemic practices, that are evident in the *animals in the school-ground* unit, are:

- The framing of a genuine need to know – how do we understand the diversity and distribution of animals in the environment, and how they interact? In the sequence the students were challenged to think about how they might investigate their allocated habitats in terms of the processes of data generation and how to represent what they found.
- At each point in the unit the classroom discussion was open and interspersed with representational challenges. The discussion was built around the generation of ideas of animal diversity, structure and function, and adaptation, and teachers mostly introduced canonical ideas as tools offered as solutions to agreed problems.
- The class operated as a community of practice at a number of levels; that of whole class agreement on processes (strongly framed by the teachers but in an important sense open to variation), group generation of data and interpretations, and individual commitment to exploration.

Wenger (2006) talks of a community of practice as involving sharing a concern or a passion for something they do and learning how to do it better through interacting regularly. He identifies three elements of such a community that need to develop simultaneously: 1) the domain, which is the shared interest around which members collectively learn from each other, 2) the community, collaboratively engaged in activities and discussion, and 3) the practice, what members 'do' when they interact. These three elements were all in evidence throughout the animals unit.

During the unit the students, together with the two teachers, operated as a community to establish and communicate practices in exploration, reasoning and explanation. The groups exploring their habitats developed their own representational systems including language, and these were further shared in the class in what became a common purpose of locating, identifying, describing and modeling animals through writing and drawing, internet searching, digital microscope images, gesture and talk. This was achieved through frequent classroom discussion of ideas, common tasks and opportunities to collaborate, and a communication focus. The unit, through emphasizing the generation by students of their own representations, and reasoning practices, exemplifies the discursive nature of learning as knowledge generation rather than simply knowledge reproduction. These classroom practices, while not 'authentically scientific' in a number of senses of professional practice in science are nevertheless closer to the knowledge producing practices of science than is the case with more transmissive approaches to teaching and learning science. For these students, the knowledge they generated and shared was new to themselves.

In coming to know and use the discursive practices appropriate to investigation of animals, students moved along a trajectory from being legitimate peripheral participants (Lave & Wenger, 1991) to a core role within the learning practices of the community. Their learning, which could be cognitively viewed as acquisition of concepts (diversity, classification, distribution, structure and function, interdependence), was situated within the social context of the classroom community, involving engagement with a set of discursive practices built around a need to know.

The Nature of Science

Traditional versions of the nature of science (NOS) tend to characterize it in terms of universalizing statements (such as that there is a fundamental distinction between theories and laws, that science involves human imagination, that scientific knowledge is subjective, and tentative and subject to change, or that scientists' work is culturally influenced – Lederman & Lederman, 2012). Osborne et al. (2003) identified a set of themes on the basis of a Delphi study involving different communities knowledgeable about science, including the role of scientific methods and critical testing, creativity, and the human nature of science.

However, others have argued that the nature of science is better seen in terms of situated practice whereby knowledge is built through a process of community representation and model generation, in a highly contingent and contextual process (e.g. Nersessian, 2008). Latour (1999) argues that the theory – evidence relationship that is so central to any characterization of NOS is best seen through a process whereby data is generated and transformed through in a series of 'representational passes'. A key feature of a pragmatist understanding of the NOS must be the evidential trail through which data is represented and re- represented in theory development and interpretation.

In the animals unit, students completed a pre test which included a 'working as a scientist' probe: A diagram shows two scientists looking at a forest floor, with the explanation that they are researching a particular small beetle that lives in the leaf litter. The questions were: What questions might the scientist ask? What are some methods they would they use to answer these questions? What would their journal look like? Students found this difficult to answer, with responses being often non-scientific, or trivial. In the post – test with the same probe, the responses were considerably more sophisticated. Figure 10.3 shows one of the more sophisticated responses showing the range of investigative understandings demonstrated.

We argue that the representation construction approach provides a significant way forward for science classroom practice through the fresh way it interprets and aligns with the epistemic practices of science. The approach, and the theoretical perspective underpinning it, aligns with significant contemporary research directions on science epistemic practices that emphasize the contextual and cultural nature of knowledge production (Nersessian 2008; Duschl & Grandy 2008), and the key role of representational practices in generating and justifying theory (Latour 1999; Pickering, 1995). Compared to more idealized versions of the NOS which focus on relations between theory and evidence viewed through a Kuhnian lens of socially determined paradigm shifts, this pragmatist semiotic perspective provides a more grounded education for students in the way it models the chains of representational transformation that characterize theory building from evidence in science, and discussions about the adequacy and the role of models to represent natural phenomena. Thus, there is a natural alignment here between the processes and the conceptual products of science, and classroom practices and practices in science.

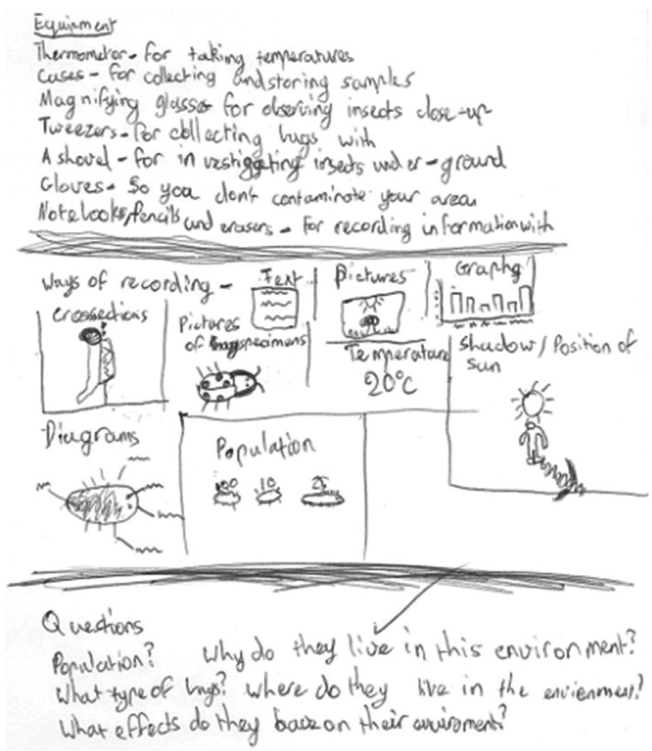

Figure 10.3. Post-test response describing equipment, recording and questions for an environmental study.

The Nature of Knowledge and Learning

The concept of animal diversity was instantiated in this unit through a variety of representational practices such as animal tallies, graphs, classification keys, drawings, and Venn diagrams. To develop a comprehensive understanding of diversity would involve being able to coordinate these representations into a coherent explanatory narrative in response to a question or a problem.

A concept such as *animal diversity* can only be thought about and communicated through constituent representations, and conceptual understanding cannot be separated from the capacity to work with these representations. Figure 10.4 is an attempt to illustrate the way these representational practices might be imagined to cluster around the diversity concept. To fully explore each aspect of the animal diversity concept would require using a number of representations, each partial yet specific, in elucidating an aspect of diversity. The concept of diversity is (incompletely) composed of this set of representations. For the students in this study, the representations of figure 10.4 were the reasoning tools by which they came to understand how the concept is used in science, to make sense of phenomena and construct and communicate explanations.

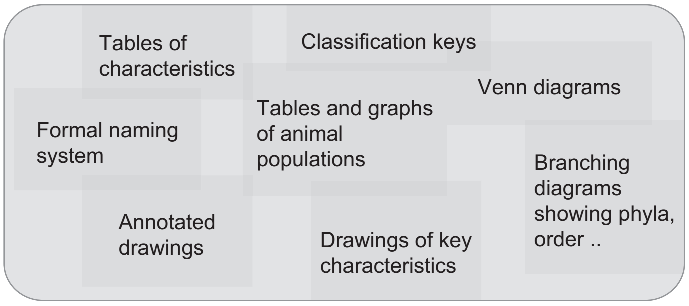

Figure 10.4. The representational practices constituting the concept of 'animal diversity'.

Curriculum designers in science typically focus on identifying clusters of concepts that comprise a topic, often not specifying what might count as evidence of students' learning of these concepts. While accepting the convenience of this approach, with its implied distinction between an idea and its expression in practice, we would argue that it does a disservice to the richly representational practices of science. The representation construction approach focuses on developing students' representational resources in a context of representational challenge and problem solving. Nevertheless a key moment in the planning is the identification of representations that relate to key ideas clustering around target concepts. The question thus becomes – what do we mean by 'concept'?

In the conceptual change literature, this question of the nature of a 'concept' is far from resolved (Vosniadou, 2008; Taber, 2011). A pragmatist perspective considers the meaning of terms to be instantiated in cultural practices, and argues they should not be idealized beyond these practices (Wittgenstein 1972). We argue that it is fruitful to think of concepts as privileged linguistic markers through which conversations in the domain can productively proceed. Concepts are core entities within the language practices of experts discussing learning and knowing in science. Thus, while understanding *animal diversity* implies a capability to select and coordinate a range of verbal, mathematical and visual representations, the conceptual term is useful for someone who has achieved such a capability, to converse with others with similar capabilities ('understanding') without the need for further explication. Thus in this unit, terms like 'animal diversity', and 'adaptation' were used in conversation to demarcate an area, but the real work of situated interpreting, reasoning and communicating was done through the associated representational practices.

Privileging of 'concepts' performs a very valuable function in enabling flexible communication around a conceptual area, and acting as a marker in higher level discussions. Concepts are used as organizing entities to shape learning sequences. The danger is that if we ascribe to a concept a resolved mental existence (rather than recognize it as standing for a range of representational practices), then we run the danger of misrepresenting the learning task. To 'achieve' a concept involves a degree of mastery of a range of constituent representational practices. We argue that the learning issues identified so thoroughly in the conceptual change literature are fundamentally representational issues, and the learning task involved in achieving the required shifts needs to be conceived of in terms of building students' requisite representational resources.

Quality Learning

The characteristics of quality learning from this sociocultural, pragmatist semiotic perspective, as described in the sections above, fundamentally involve active and increasingly competent participation in the representational / discursive practices of a classroom built around guided inquiry. In the set of principles described in Chapter 3, the process of learning, and effective support for learning, are characterized by representational challenges in which students generate representations in response to an established problem, and these are subject to public or group negotiation and refinement. In this process there is generally a strong link between the representations and perceptual experience, characteristic of idea generation in science more generally. The representational refinement process involves an interaction between individual representations and the canonical representations of science as introduced by the teacher.

Thus, students in representing animal diversity constructed their own drawings, but drawing conventions such as scale were discussed. Increasingly students had access to drawings and classification keys through the internet so that canonical representations were increasingly accessed. Teachers made formal presentations of some representations such as branching diagrams in introducing formal animal groupings. Thus, while the conditions for quality learning include active representation construction, in some cases this means representational challenges prior to the introduction of canonical forms, in other cases canonical forms are introduced prior to construction involving variation of these to solve contextual problems. This variety of forms of representational challenge was discussed in Chapter 4 in relation to the structures of learning sequences.

The argument for active construction of representations as a key condition of quality learning, rather than as a major focus on interpretation of canonical representations, is based on at least four positions:

- Learning, conceived of as involving increasingly competent participation in the discursive practices of the science classroom, inevitably must involve active engagement with these practices rather than simple exposure to and interpretation of them.
- The act of constructing representations focuses student attention on the particular affordances of the mode and form, which act to constrain thinking and channel attention on selective features of phenomena. Thus, with the centipede modeling described in Chapter 6, each mode offered a specific, different but complementary version of the animal's movement.
- Actively constructing representations attunes students to features of the problem space, and prepares them to appreciate canonical solutions introduced by the teacher (Schwartz & Bransford 1998). Thus, finding and describing and then identifying a variety of animals through a series of representations prepared students to actively engage with classification keys and drawings and naming systems in their internet searches.
- Students' learning capacities are often in advance of their demonstrated developmental level, and students therefore benefit from opportunities to perform representational tasks before they have achieved full competence in these tasks (Cazden 1981, following Vygotsky 1978).
- Quality learning also involves epistemological understandings about the nature of models/ representations and their selective purposes. This meta representational knowledge arises from explicit discussion of representations, and feeds back into selection and refinement processes.

There has been considerable comment in many countries about students' lack of engagement with science and declining enrolments in science courses (Tytler, 2007). Interview studies have linked this with the transmissive pedagogies associated with traditional science classrooms, and the fast pace and shallow coverage of content forced by many science curricula (Osborne & Collins, 2001; Lyons, 2005). There is some suggestion also that this engagement issue has an identity dimension, in particular that for many students a subject that is very authoritarian in approach, that does not allow students to express imagination or personal perspectives and opinion, is incompatible with their expectations of a fulfilling identity (Haste, 2004; Lindahl, 2007; Schreiner & Sjoberg, 2007). Quality learning, from this perspective, must involve the capacity for students to align the science they are learning with an identity that is attractive to them, and this involves for many students a sense of agency in learning, and opportunity to express themselves. We argue that the representation construction approach encourages students to imaginatively respond to challenge and to allow room for individual expression of understanding. It does this while maintaining a strong conceptual agenda managed by the teacher, at a slower pace but deeper level than traditional approaches. In this way the approach is a serious attempt to balance the need for inquiry and individual expression, with the need to introduce students to canonical content and practice.

There is a considerable body of research on the impact of identity on young people's educational engagement (Tytler & Osborne, 2012; Archer, Hollingworth & Halsall, 2007). Glen Aikenhead (2005) argues that for many students, especially indigenous students, 'to learn science meaningfully is identity work' (p. 117). He argues that presenting science as value and context free, without multiple or contested views, tends to marginalize some students on the basis of their "cultural self-identities" (Aikenhead and Ogawa, 2007, p. 540). The identity work at stake has been explored for a range of cultural and other groups including Maori women scientists (McKinley 2005), minority females in the US (Johnson, 2007), and marginalized groups in many countries. Researchers working in a critical sociocultural tradition see the issue as representational in nature (Moje, 2007), in that the problem centres on negotiating the representational resources of cultural groups with the canonical representations of science. While the RiLS project did not tackle this issue directly, we argue that student construction of representations, and the challenge and explicit negotiation involved in assessing these and aligning them with canonical forms, offers the possibility of acknowledging and negotiating different representational traditions to engage all students in the discursive practices of mainstream science, flexibly conceived. The process, properly managed, is capable of opening up multiple identity possibilities through these representational deliberations. The representational challenges, seen in this way, become boundary objects (Akkerman & Bakker, 2011) through which students learn to take on science-engaged identities.