CHAPTER 5

LEARNING THROUGH THE AFFORDANCES OF REPRESENTATION CONSTRUCTION

In this chapter we draw upon several theoretical perspectives and past research into language and learning in science, to develop a framework to characterize how and why student engagement in representation construction practices supports learning in science. In developing this framework, we integrate literature on the role of symbolic tools in facilitating learning, and then focus in detail on the particular advantages of representation construction in learning in science. The chapter parallels an argument developed in more detail elsewhere (Prain & Tytler, 2012).

LEARNING THROUGH REPRESENTATION CONSTRUCTION

As argued in previous chapters, there is growing research interest in the value of students being guided to generate their own representations in science to support learning. This is evident in research on learning through drawing in science (Ainsworth, Prain & Tytler, 2011; Ainsworth, Musgrove & Galpin, 2007; Van Meter & Garner, 2005), studies of visual/spatial reasoning (Mathewson, 1999; Tversky, 2005), and templates developed to guide reasoning processes in inquiry (Keys, Hand, Prain & Collins, 1999). Our own research, described in Chapters 2 to 4 of this book, has indicated conceptual gains and high levels of student engagement with learning and reasoning arising from student-constructed representations (Waldrip, Prain & Carolan, 2010; Hubber, Tytler & Haslam, 2010; Hubber, 2010). In Chapters 1 and 3 we argued that there are strong justifications for this representational work.

The essence of this teaching and learning approach, in a process tracked in the earlier chapters of this book, involves teachers supporting students to construct representations of phenomena and refining these through coordinated public discussion of their explanatory adequacy. Students’ representations are loosely scripted, and therefore in an important sense non-standard, or “approximations”, but during the learning sequence students are led to understand and appreciate canonical scientific representations. We have argued that this approach brings classroom science closer to the knowledge-building practices of science itself.

R. Tytler, V. Prain, P. Hubber and B. Waldrip (Eds.), Constructing Representations to Learn in Science, 67–82.
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As an example, we take the representational challenge activity described in Chapter 1, where students constructed a model of the movement of a chosen animal. Two students chose to represent the extension and retraction of an earthworm as it moved, using an abstracted model in which an elastic material was manipulated to quantitatively duplicate the earthworm’s movement. Their account showed a complex weaving between observations of the animal, measurements, the drawing, and the model as they tested materials to provide a valid reconstruction of its movement. The core of our argument in this chapter is that in this case of understanding animal movement, each representational mode the students develop offers productive constraint in what they can draw and model as they attend to the demands of the task, the resources available, and the opportunities for observational checking of the animal. The students need to focus selectively on the details of the movement and the underpinning earthworm structures. In this and in other representational challenges students are supported to coordinate semiotic tools such as annotated drawings, physical models and graphs, and material tools such as quadrats or digital microscopes or rulers, to generate specific understandings of aspects of phenomena. Through this work, students engage with authentic scientific knowledge-building practices in developing representations to make claims and develop explanations. We argue, on the basis of our experience of these cases, that reasoning based on representational construction leads to quality learning, and in this chapter we explore just how and why this might be the case. At the heart of our argument is the idea that representational work productively constrains the focus of student meaning-making.

THEORIZING HOW MATERIAL AND SYMBOLIC TOOLS SUPPORT LEARNING IN SCIENCE

A major tradition in educational research over recent years has involved a focus on the role or roles of material and symbolic tools in supporting student learning. This research has been framed broadly within either cognitive or sociocultural accounts of interactions between learners, resources and contexts. Cognitive accounts focus on individual learners’ mental strategies in engaging with these tools and ideas, while sociocultural accounts focus on the design features of these tools, and the nature of the practice in using them, that drives collective learning in the classroom. From cognitive perspectives, learners develop mental models, schemas, organizing strategies and frameworks to learn from interacting with these tools (Piaget, 1969; Bruner, 1966). From sociocultural perspectives, these tools are cultural resources, and learners need to participate in authentic activities with these tools to learn effectively (Cole & Wertsch, 1996; Vygotsky, 1978). Vygotsky’s (1981b, p. 141) concept of “mediation” has been widely used to characterize the interplay between learners, tools, environment, guidance, and learning. He was particularly interested in the critical role of everyday language as a symbolic tool for learning the languages of science. He also acknowledged that other symbolic tools, such as algebra, writing,
diagrams and “all sorts of conventional signs” (Vygotsky, 1981b, p. 137) were critical mediating tools for this learning. The idea of mediation is our starting point for analysing current theories of the role and processes of symbolic representation in learning science. There is now broad agreement that school science students need to learn how to interpret and construct subject-specific representations of science concepts, methods, and processes. There is extensive research on what and how students learn from interpreting expert representations (Ainsworth, 2006, 2008; Gilbert, 2005), drawing on cognitive perspectives to provide theoretical justifications for why this learning is enabled (Ainsworth, 1999; Mayer, 2003; Paivio, 1986). However, there is a paucity of research into student-constructed representations, or theoretical justification for this approach. One reason for this is the view that the goal of induction into the literacies of science is achieved more efficiently through an explicit focus on conventions rather than through an open-ended constructive process. There are also concerns about the manageability for teachers in encouraging student constructions, particularly when students generate non-standard representations. Indeed, our research has indicated that a focus on student-generated representations makes significant demands on teachers’ conceptual understandings and classroom time (Hubber, Tytler & Haslam, 2010).

In our argument we draw on literature dealing with student representational construction, (Bransford & Schwartz, 1999; Cox, 1999; diSessa, 2004; Greeno & Hall, 1997; Kozma, 2003; Kozma & Russell, 2005) and extensive analyses of the student representational work from our research over 7 years on teacher-guided, student-generated representations. From this pulling together of literature and our own experience, we have proposed a framework of Representation Construction Affordances (RCA) to explain how and why students learn from this work (Prain & Tytler, 2012). This framework interconnects three dimensions to explain how and why this representation construction work supports quality student learning. These dimensions are:

- The *semiotic* processes where learning is understood as students developing the capacity to recognize and use key features of generic and science-specific material and symbolic tools to interpret/explain phenomena;
- Meaning-making at the *epistemic* level, where knowledge building in science is understood as the use of a broad range of material and symbolic practices for undertaking and communicating science inquiry, and our argument that these practices should be strongly reflected in classrooms; and
- Meaning-making as an *epistemological* activity, where student reasoning and learning in science can be enhanced by the process of constructing and negotiating their own representations.

The RCA framework integrates these perspectives and resources by conceptualizing them as necessarily interdependent. However, in this chapter we only have space to sketch out the broad terms of our case. In our account, student-generated
representations include oral and written language, and mono- and multi-modal texts, artefacts, and mathematical calculations. Specific examples include tables, diagrams, observational and conceptual drawings, graphs, annotated self-explanations, visual summaries, video productions, animations and 3D models. In the chapter we focus predominantly on drawing, as indicative of our case.

Previous accounts of the value of representation construction practice draw mainly on sociocultural perspectives, considering the potential for increased student engagement in a learning community (Greeno, 2009; Kozma & Russell, 2005). There is a lack of more varied and persuasive literature examining the value of this type of representational work. From a cognitive perspective, Bransford and Schwartz (1999) sought to re-conceptualize the learning gains and potential for transfer when students generated their own representations. They claimed that student construction of representations led to the development of problem-solving skills that could be applied in new contexts, arguing that in constructing their own representations students were productively constrained in their reasoning by having to focus on key aspects of the problem, select appropriate tools, and apply relevant background knowledge to the problem. The idea that the use of particular material tools productively constrains scientific inquiry is well-recognized (see Pickering, 1995), as is the productive constraint of symbolic tools and processes. Kozma (2003, p. 205) found that expert chemists, in manipulating representations, used the material features within and across different representations to “reason about their research and negotiate shared understandings”, and argued that students could develop this capacity through teacher-guided use of interaction with expert representations. Kozma and Russell (2005, p. 129–30) argued that students learn science effectively when they participate in activities “in which representations are used in the formulation and evaluation of conjectures, examples, applications, hypotheses, evidence, conclusions, and arguments”.

These general accounts of student learning gains from constructing representations highlight the need for a framework that recognizes the necessary interplay between student capacities and intentions and task and/or tool design features. They also highlight the key role of the learning context — the purposes and procedures of this representational work. However, these questions raise the issue of what particular student capacities are required or supported by this process and what particular supports might enable this work. In making this analysis we need to develop an account of learning in science, and how learning relates to representation production.

Gibson (1979, p. 5; 1986), seeking to move beyond a focus only on an individual’s mental processes to explain perception, theorized that individuals interact with the physical environment in terms of “affordances” that support their goals or intentions. Individuals recognize a required potential action that the environment both prompts as well as supports. This account of affordances has been productively used in various domains, especially in computer program design, and problem solving. Seeking to
further clarify this construct, Norman (1999, p. 39) considered that all affordances are “perceived” affordances, in that the enabling feature in the environment needs to be noticed to be enabling. He argued that affordances are best understood as physical enablers and constraints. Both Gibson and Norman were more concerned to explain purposeful perception rather than account for exploratory or learnt behaviour with symbolic or material cultural tools. However, we argue that this idea of affordances as enabling constraints can be applied productively to understanding how and why generating representations supports learning in science. We extend the idea of affordances as perceptual interactions with the environment to include learnt behaviours and strategies in the classroom. We argue that particular material and symbolic tools offer specific affordances for students constructing a representation to develop an explanatory account.

LEARNING THROUGH STUDENT-GENERATED REPRESENTATIONS

Our theoretical framework (RCA) integrates semiotic, epistemic, and epistemological perspectives to explain how and why representational construction supports learning in science (see Figure 5.1). In this nested Venn diagram, each dimension is linked by its focus on the way representations productively constrain meaning-making practices in science and in science education. Within each dimension there will be interplay of diverse cultural and cognitive resources students or scientists bring to achieving this meaning-making. The circles move from the general semiotic dimension, acknowledging the role of material and cultural artefacts in learning and knowing, to the particular epistemic processes through which public knowledge is generated and validated in the scientific or classroom community, to the dimension where reasoning through these resources generates individual or group meaning. Each circle indicates the cultural and cognitive resources, as well as the practices and processes that are involved in this work. The nested Venn diagram provides a window into our framework but we acknowledge the figure on its own may not adequately signal its complexity. The diagram is intended to suggest an indicative map. The arrangement of the diagram reflects our major focus on characterizing students’ learning processes. If the focus was on science teams, a different representation may be more appropriate.

Semiotic Dimension

The largest circle focuses on the broad material and symbolic cultural tools available for meaning-making generally. These tools include generic as well as domain-specific resources. This characterization is consistent with recent cognitive science, and sociocultural perspectives regarding the centrality of language or languages in mediating learning (Tytler & Prain, 2010). Constructing a representation is constrained productively by its purpose, context, and the various physical and conventional resources available for any particular type of
representation. For instance, when making a drawing of a process, students are constrained by the physical space available, the conventions they can deploy, their form/function limitations, the need to achieve specificity of detail, and the requirement of unambiguous communication. A drawing is forced to be more spatially specific, for instance, than a verbal representation. Properly scaffolded, these constraints can serve to encourage students to engage with the succinctness and adequacy of conventions in constructing explanatory accounts. Trying to represent key features or causal factors in a dynamic system with pen and paper tools poses different challenges from using animation to achieve the same goal. The representation-maker is compelled to be specific in selection of details, to engage with issues of emphasis, layout, adequacy, and fit for purpose in ways that interpreting existing texts do not necessarily foreground. Thus, the constraints
offered by particular representational modes and tasks enable reasoning and learning precisely because of the specific ways they channel attention, and force choices by the person or group constructing the representation. For example, when making a video explanation of a scientific process, students are productively constrained by the need to synchronize sound, text and image to make their representational case coherent to themselves and others. Students also need to understand the partial nature of representations, where each representation serves to focus attention on a specific aspect of a problem, and that generating an explanatory account involves coordinating a variety of representations, each bringing a complementary perspective.

Representational competence plays a crucial role in developing conceptual learning in science (e.g. Lemke, 2004; diSessa, 2004; Lehrer & Schauble, 2006a). This competence is about knowing how to interpret and construct links between an object, its representation, and its meaning (Lemke, 2003; Peirce, 1931–58). A representation becomes a sign when it signifies something (a key idea or explanation) about the object (or referent) to someone (the learner). Meaning-making practices in school science can be understood in terms of Peirce’s (1931–58) triadic account of the components of this meaning-making. In this model, distinctions are made between a representation or sign (for example, arrows in diagrammatic accounts of force), the interpretation or sense made of this sign (the scientific idea of force), and its referent (the phenomena to which both the interpretation and signifier refer, such as the specific operation of force on objects in the world). This implies that for learners to understand or explain concepts in science, they must use their current cognitive and representational resources to learn new concepts at the same time as they are learning how to represent them. Learning concepts in science involves students switching between representational modes (verbal, written, visual and mathematical), and coordinating these to generate explanations. There is a growing recognition that students need to acquire competence in these discursive science practices to achieve science literacy (diSessa, 2004; Gilbert, 2005; Kozma & Russell, 2005; Lemke, 2004). Our own research on student-generated representations (Waldrip, Prain & Carolan, 2010; Hubber, Tytler & Haslam, 2010; Tytler, Haslam, Prain & Hubber, 2009; Tytler & Prain, 2010), and research by others in this area (Cox, 1999; diSessa, 2004; Ford & Forman, 2006; Greeno & Hall, 1997; Lehrer & Schauble, 2006a) suggests that this representational work has the potential to increase students’ understanding of the form/function relationships in various representations, enabling students to understand the value and use of conventions in this work.

**Epistemic Dimension**

The “epistemic practices” circle focuses on the knowledge building and validating and checking processes, as well as communicating practices, that constitute the
discipline of science and its literacies (Ford & Forman, 2006; Moje, 2007). There is a growing literature on the role of representation, including visualization, as central to knowledge production practices in science. A considerable body of research confirms the central role of representation in generating, integrating and justifying ideas in historical scientific developments, and thus in contributing to knowledge production. In Chapter 1 we discussed Gooding’s (2004, p. 15) highlighting of the central role of representational refinement and improvisation in his account of Faraday’s work on conceptualizing the interaction of electricity, magnetism and motion, and Latour’s (1999) account of the process by which data is transformed into theory through a series of representational “passes”. Nersessian (2008, p. 69), in examining cases of innovation in science using case studies of Faraday and Maxwell and more recent work, argued that model-based reasoning is critically important to the generation of new theory and that the productive interaction of models is the key to this process. On the basis of analysis of idea generation in a contemporary scientific laboratory, she supported Hutchins’ (1995) notion that ‘cognition’ and ‘culture’ should be seen as interrelated in scientific processes, and that problem-solving in scientific and engineering domains should be viewed ‘as occurring within complex cognitive-cultural systems’ (p. 71).

There is growing agreement that classroom practices in science should be organized to practice these representation construction processes to provide an authentic induction into science learning (Duschl & Grandy, 2008). A long tradition in science education has sought to integrate the processes and products of science into a coherent set of science education practices. However, at various times a process or a product focus has been in the ascendency, largely treated separately, and conceptualized as distinct. For instance, ‘working scientifically’ strands tend to address measurement in science, the nature of investigable questions, and such issues as appropriate design built on levels of sophistication of variables control, without strongly linking these to knowledge generation. The argumentation perspective looks at the way evidence is used to select between alternative positions and how knowledge claims are justified with evidential backings that can withstand alternative positions. These perspectives have tended to explore the public justificatory processes through which scientists can claim their work as verified against possible alternative findings, but do not adequately represent the situated, successive cuts and thrusts of data generation and representation that characterize on-the-ground knowledge building and verification. There is need for learning in science classrooms to focus on the processes by which communal knowledge is built, as well as the means by which this knowledge is defended and established.

To adequately capture in classrooms the scientific generation of knowledge, there is a need to foreground representational generation, coordination and transformation rather than mainly focusing on formal aspects of argumentation and ‘scientific method’. Duschl and Grandy (2008) argued that attempts to define a general
inductive rule for specifying the scientific method have been a failure and that we must see scientific methods as contextual, local, and contingent. They claim there have been three phases to understanding the nature of science: 1) logical positivism (the received view) that underpins traditional versions of scientific method, 2) paradigm shifts / conceptual change views that admit social processes, and 3) model-based science with acknowledgement of the centrality of language, representation and communication. Student representation construction, in our view, is an approach that enacts new and fresh pedagogies consistent with these recent understandings of the relationships between process, product and language in learning science.

Epistemological Dimension

The “epistemological processes” dimension indicates the diverse range of cognitive processes entailed in reasoning with and through representation construction at an individual or group level. There is growing acceptance that the representational tools of science are crucial resources for speculating, reasoning, constructing and contesting explanations, theory-building, and communicating. For Nersessian (2008, p. 77–78) model-based reasoning by scientists is enabled through the explicit, productive constraints that operate in the way knowledge is represented. These constraints also enable reasoning processes, including making abstractions (limiting the case, or making generalizations), using simulations, evaluating particular cases (identifying the degree of fit, the explanatory power of a case), and judging the coherence of a claim.

This construction and justificatory work can serve a very wide range of reasoning moves and cognitive purposes. Cox (1999) noted that representations can be used as tools for many different forms of reasoning, such as initial, speculative thinking, as in constructing a diagram or model to imagine how a process might work, or to find a possible explanation, or see if a verbal explanation makes sense when re-represented in 2D or 3D. They can also be used to record precise observations, to identify the distribution of types, to show a sequence or process in time, to predict outcomes, sort information, and to work out reasons for various effects. Students need to learn how to select or develop appropriate representations to address particular needs, and be able to judge their adequacy for purpose. Ford & Forman (2006) argued that reasoning in science needs to have a purpose and that active generation and evaluation of representations in pursuit of investigations captures the nature of science knowledge building practices in ways that formal reasoning schema (such as argumentation) do not.

A strong cognitivist tradition in science education has led to concepts and representations being viewed as separable from one another, with representations held to be subordinate approximations or accompanying pictures of concepts that exist independent of, and prior to, any particular representational instantiation. However, any attempt we might make to explicate a concept in science makes
it apparent that the concept can be understood and applied only through a range of associated representational practices and conventions. Thus, to understand chemical bonding requires familiarity with conventions of molecular representation, bonds, and electron energy and orbital representations. To use this concept to develop an interpretation or explanation in any particular context requires flexible coordination of these representations, possibly together with the generation of a range of non-canonical representations such as gestures, annotations and verbal descriptions.

Lemke (2004) and others have noted that although the same idea in science can be represented variously, no shared scientific idea exists separate from its representation. Any explanatory account of ideas in science can only be communicated in different or new representations. Thus, the production of shared scientific meanings and reasoning cannot transcend representations, together with their productive constraints. Meanings in science are always represented meanings. As noted by Kozma and Russell (2005, p. 129), “the meaning of a representation is not embedded in the representation itself but is assigned to the representation through its use in practice”. We have argued elsewhere (Tytler & Prain, 2010) that this insight tends to recast conceptual learning in science as fundamentally about the coordination and facilitation of different, multi-modal representations. This implies that when students focus on the purposes, adequacy, claims, and applications of representations to particular contexts, they are engaging in crucial aspects of learning or coming to know in science, where representational work functions as a tool for knowing and making claims.

A LESSON ON EVAPORATION: ILLUSTRATING THE RCA FRAMEWORK

To explore the ways in which representational challenges can open up reasoning and learning opportunities, through this notion of productive constraint, we will describe the interactions in a lesson from the Grade 5/6 (age 10/11) water sequence involving a series of representational challenges designed to establish a molecular model of the process of evaporation. This analysis has been previously presented in some detail (Prain & Tytler, 2012). The lesson description below summarizes the events in the third lesson in a sequence of seven, on evaporation. Each lesson posed a challenge for students to explore and represent, based on molecular ideas. Prior to this third lesson students had been challenged to explore and represent a variety of places in the school where water is found, in different forms. In the lesson described below, the molecular representation is introduced and refined, after the idea of molecules was introduced by students and discussed in the previous lesson. This aspect of the sequence is discussed in more detail in Chapter 6. The description is structured to show the different representations that are introduced and used at each point, key teacher moves that are made (in brief), and sample student responses and representational moves.
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A Sequence of Multi-Modal Representational Challenges

<table>
<thead>
<tr>
<th>Representation</th>
<th>Teacher moves, student actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video of puddle evaporating.</td>
<td>T1 summarizes video issue concerning energy required to evaporate the puddle. There is a brief discussion leading to the question: What is actually going on?</td>
</tr>
<tr>
<td>Role-play</td>
<td>T1: You are all water molecules. I want you to imagine you are water molecules, in the solid state, I want you to move to show me what you would look like. Students discuss movement: No, each one sort of moves – [pushes the other student and moves to and fro]</td>
</tr>
<tr>
<td>Teacher uses jiggling body to emphasise movement.</td>
<td>T2: They [students] are moving, is that correct? Do molecules in a solid state move? T1: Yes they move.</td>
</tr>
<tr>
<td>Use of role-play to have students simulate solid, liquid, gas</td>
<td>T2 leads question-response discussion where he establishes the greater movement in liquids (students model a liquid compared to solid) and increased spacing for gas: Gas! Show me! Students move away from group members, scattering around the hall. All continue vibrating</td>
</tr>
<tr>
<td>Drawing challenge: show solids liquids, gases.</td>
<td>T2: Have you shown what is the difference between solid water molecules, liquid water molecules, and gaseous water molecules? Did you show that difference? You have bodily moved, very well … how would you indicate that in a diagram? Students draw molecules in the solid, liquid and gas states (Figure 5.2)</td>
</tr>
</tbody>
</table>

Figure 5.2. Student drawing of molecules in the solid, liquid and gas states.
V. PRAIN & R. TYTLER

<table>
<thead>
<tr>
<th>Representation</th>
<th>Teacher moves, student actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher uses beads now to model a focus on individual molecules responding to an energy source – vibrates them – some spill.</td>
<td>T1: Come back again to that gas molecule ... when we had that heat source, that energy coming in is this what happens? A student comes to the container, picks up a bead and moves his hand in a haphazard motion above the head. T1 challenges this by demonstrating dispersal by shaking beads out – models randomness of distribution T1: Which molecules are the first ones to go? Students: Top ones ... Ones that had started moving faster ... More heated ones ... Ones that get more energy</td>
</tr>
<tr>
<td>Bead demonstration</td>
<td>T1: In your diagram, there may be need to show a three dimensional diagram or a series of diagrams, think about not just two-dimensional. T1: Okay let us give these molecules, beads, a human form [picks up a bead and points to it]. Here is George, he is here vibrating in water as a solid, then there is more energy he moves more in a liquid state, and then here is Molly ...</td>
</tr>
<tr>
<td>Drawing challenge</td>
<td>T1: Tell me a story about one water molecule, about what happens to it. Let’s do it in four frames. Remember, label, say why is he here, what does he actually need? Students work on their diagram narrative (Figure 5.3)</td>
</tr>
</tbody>
</table>

Figure 5.3. A student narrative diagram showing an individual molecule.
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The lesson begins with a video presentation of evaporation. The teacher’s question ‘what is actually going on?’ (Move 1) is used to introduce the notion of molecules through a role-play. The teachers (T1, a male, and T2, a female, are co-teaching a composite Grade 5/6 class of 50 children) then use a sequence of representational moves and challenges to open up, negotiate, and come to some agreement concerning the different molecular representations of the states of matter and the evaporative process. The lesson ends with a verbal review of the key features of the molecular model.

Features of the sequence illustrate the ways in which representations are critical to learning, reasoning and knowing in science, and the way these relate to the RCA framework of Figure 5.1.

Semiotic dimension: The centrality of semiotic resources, represented in the larger circle of the RCA model, is clearly displayed in the way symbolic and material resources are woven to develop an increasingly complete picture of molecular interpretations of evaporation.

Epistemic dimension: The harnessing of representational resources to make claims and support these in a public process of evaluation and refinement mirrors the epistemic practices of science. The teacher guides the class in extending and exploring different modal representations to model evaporation in a range of contexts.

Epistemological dimension: Students come to know in science through the negotiation and refinement of multi-modal representations, and the integration of these with phenomena, to build personal meaning.

The specific purposes of each representation can be seen to match the affordances it offers. In the analysis we can identify enabling constraint as a productive characteristic of each representational resource – each representation constrains what is focused on and what can be imagined about the process of evaporation. For instance the role-play (moves 2–4) gives a strong embodied sense of the movement of molecules. It focuses attention on spacing and movement by placing constraints on molecular size. In so doing it opens up possibilities for exploration of the affordances of the representation, which in this case was taken up by the students and teacher (moves 2 and 3), when the group of students was confronted with the question of whether they should remain still or move. Their decision to move could be seen as a case of speculative reasoning, perhaps grounded in the embodied nature of the task. In this case as with all these representational challenges, students are driven by the role-play to discern and integrate different aspects of the representation. This, in Schwartz and Bransford’s (1998) terms, amounts to the discernment of features of the representational problem space – how might we imagine molecules behaving? In Cazden’s (1981) terms, the students are being required to perform before they are competent. They are required to make choices and coordinate and discern the possibilities and challenges posed by the representation. In the drawings (move 5) the visual / spatial choices encouraged students to think about spacing, number, size, and speed, and how to represent these.
In move 7 the bead model acts as both a material tool and a semiotic tool. Insofar as it is introduced by the teacher it is a semiotic tool to be interpreted, but in asking the student to come forward and demonstrate what happens to an individual molecule responding to energy, that student becomes a representation-maker utilizing the material beads. The student is challenged to sort out the possibilities of the representation while enforcing a consistency with what has come before with the role-play. The focus has moved from macro to micro, involving the construction a new explanatory account requiring new representational coordination. The subsequent comment and counter-demonstration by the teacher along with questions about the order in which molecules ‘go’, constrains thinking by focusing the task on individual molecular-energy interactions. The narrative drawing constrains and focuses attention on the ongoing history of a molecule that is neither created nor destroyed. A key productive constraint of the molecular model is its natural adherence to conservation of matter. The time sequence drawing of the states of matter in move 8 constrains the way the different states can be imagined by forcing attention on coordination of properties (number, size, spacing and arrangement, movement) across the states.

DISCUSSION

In this chapter, and throughout this book, we have argued that there are particular learning gains for students when they construct, negotiate, refine and justify their own representations of scientific processes and concepts. These processes enable students to:

- learn conceptual knowledge through enacting the epistemological practices of the science community, experiencing the challenges of explaining and justifying scientific causal explanations through representations (such as drawings and models);
- learn the nature of scientific inquiry through participating in knowledge-production practices as an authentic induction into those broader practices through which scientists construct representations to generate and justify knowledge claims; and
- learn the literacies of science and their rationale, acknowledging the semiotic aspects of knowledge and communication in science. For us, communication is not simply the final stage in a process after mental work, but rather part of the process of developing representations to produce explanatory/interpretive accounts, first for the self, then for others.

Our framework conceptualizes these semiotic, epistemic, and epistemological practices and resources as overlapping and intersecting through guided student representation construction work. In this way we seek to explain why this representational practice engenders quality learning.

As discussed in Chapter 1, our theoretical framework is distinct from current socio-semiotic accounts of learning in science (e.g. Martin, 1993; Unsworth, 2001; Veel, 1996). We advocate open-ended exploratory student representation
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collection rather than highlight directed teaching practices, and identify particular affordances, or productive constraints, entailed in representation construction. The semiotic resources, epistemic practices, and epistemological processes in our model are conceptualized in Vygotskyan terms as external cultural resources that learners draw on as they represent/develop their understandings. Learners are cast in the model as active interrogators of their own representations, and their growing command of these resources involves perceiving opportunities for new connections, imaginative syntheses, and unpredictable solutions.

To explain our experience of significant, quality learning in the water and other units in the RILS project, and the apparent capacity of students to transfer learning to new situations, we draw on the ideas of Schwartz and Bransford (1998) who argued that the learning advantage afforded by active generation of representation comes from students practising discernment of the features and structures of the ‘problem space’. That is, that in grappling with the need to represent to interpret and explain phenomena, students come to differentiate key aspects and possible points of attack. Thus, in generating and negotiating different aspects of drawings and role-play representations of evaporation, students’ attention was drawn, to some extent systematically, to critical features of the molecular model such as size, distribution and speed, spacing, interaction with energy and with each other, and conservation, and to the relation of these with evaporative phenomena. The alternative conceptions literature has identified all these as representing significant conceptual difficulties for students. We now see them more clearly as representational in nature. In Schwartz and Bransford’s terms, this process of exploration supports discernment of both the relevant features of evaporation that need explanation, and the relevant features of the representations needed to make sense of evaporative processes.

It is interesting to compare the representation production work of students in the evaporation lesson described above with Kozma and Russell’s (1997) ‘curriculum of core representational competence’. This was developed, based on a comparison of expert and novice use of representations to solve problems in chemistry. They identified, as characteristics of this competence:

- The ability to identify and analyze features of a particular representation and patterns of features and use them as evidence to support claims or to explain, draw inferences, and make predictions;
- The ability to transform one representation into another, to map features of one onto those of another, and to explain the relationship;
- The ability to generate or select an appropriate representation or set of representations to explain or warrant claims;
- The ability to explain why a particular representation or set of representations is more appropriate for a particular purpose than alternative representations; and
- The ability to describe how different representations might say the same thing in different ways and how one representation might say something that cannot be said with another.
While these were based on adult chemistry expertise, all these features were arguably present to some degree in the primary school evaporation sequence, and in RILS classrooms more generally. We suggest that students, in generating and then assessing the adequacy of a range of interacting representations of water molecules in evaporative situations, were engaged in precisely the sort of flexible representational moves that draw on the particular affordances and constraints of representations, that allow high level problem solving in science.

In this book we focus on the practice of constructing representations across a range of contexts, levels and topics to support student engagement and learning in science. We have proposed in this chapter, and elsewhere (Prain & Tytler, 2012), a framework intended to make sense of why representational construction within a guided inquiry framework offers particular affordances for student learning of both the concepts of science and of scientific knowledge-building practices. The framework integrates epistemic, epistemological and semiotic perspectives to propose new insights into the nature of quality learning in science. In so doing, we propose and justify an approach to teaching and learning in science classrooms that enacts the knowledge production practices of the discipline. We believe this framework provides further insights into the Vygotskyan notion of mediation of cultural tools in learning domain-specific knowledge and practices.