A representation construction approach to science teaching and learning

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A major focus of the Representation in Learning Science (RiLS) project has been to develop a teaching and learning approach based on the central principle of student representation construction, and to investigate the nature and quality of student learning that flowed from this. The project involved refining and extending our previous explorations of such a pedagogy (Carolan, Prain and Waldrip 2008) which were described in the previous chapter, and further drawing on and interpreting a diverse literature concerning student knowledge construction and its relation to representation and modeling. This included the vast conceptual change literature, which we have re-interpreted from a representational perspective (Tytler & Prain 2010) but on which we explicitly drew for insights into the particular problems evident for students learning key conceptual schema in science. It also included the Vygotsky inspired socio cultural literature concerning the role of language and representations generally in mediating learning.

There is a substantial literature, set broadly within a socio cultural framework, arguing that learning and knowing should be seen as a process of enculturation into the discursive practices of science (Lave and Wenger **), and further that these practices are substantially shaped around a set of discipline specific and generic literacies used in science to build and validate knowledge (Moje, 2007). From this perspective, understanding is seen in terms of the capacity to generate and coordinate multi-modal representational resources to develop explanations and solve problems. Thus, explicit discussion of the form and function of scientific representations becomes a key aspect of teaching and learning in science (Ainsworth 2006, 2008; Lemke 2004). Achieving meta representational competence (DiSessa 2004) in recognizing the characteristics of effective representational practice, including representational quality, the selective nature of representations, and how they are coordinated in developing solutions, becomes a key aim of science education (Gilbert 2005; Kozma & Russell 1997, 2005; Kozma et al. 2000). A growing modeling literature identifies the power of refinement of explanatory models through classroom negotiation (Clement & Rea Ramirez 2008). The implications of these literatures for classroom teaching and learning practice is that there should be represented in the public space of the classroom the opportunity for students to develop a) explicit knowledge of representational form and function, b) knowledge of representational quality and the selective nature of representations, and c) skills in coordinating multiple representations in problem solving.

Further studies have verified the defining, rather than supporting role played by representations in the generation of knowledge and the solving of problems (Klein, 2001; Tytler, Haslam, Prain & Hubber, 2010; Zhang, 1997), consistent with pragmatist perspectives on the material nature of knowledge (Peirce 1931/58; Wittgenstein**) and the way representations actively shape knowing and reasoning. Again, from a classroom perspective this implies that rather than focus on concepts conceived of traditionally as explicitly and verbally defined, teaching and learning processes need to be built around the representational resources used to instantiate scientific concepts and practices (Moje 2007).

From socio-cultural perspectives, learners need to participate in authentic activities with these cultural resources/tools to learn effectively (Cole & Wertsch, 1996; Vygotsky, 1978, 1981a, 1981b). A further literature in science education argues the need for students to actively construct representations in order to become competent in scientific practices and to learn through participating in the reasoning processes of science (Ford & Forman 2006). Socio-cultural accounts of the value of this practice focus on the potential for increased student engagement in a learning community (Greeno, 2009; Kozma & Russell, 2005). 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. Rather than argue that students developed transferable domain knowledge from this activity, they claimed that student construction of representations led to the development of problem-solving skills that could be applied in new contexts. Cazden (1981) argued that students needed to engage with performance of representational practice before achieving competence.

Researchers in classroom studies in this area (Cox, 1999; Greeno & Hall, 1997; Lehrer & Schauble 2006a, b; Tytler, Peterson & Prain 2006; Waldrip, Carolan & Prain 2010) have noted the importance of teacher and student negotiation of the meanings evident in verbal, visual, mathematical and gestural representations in science. They claimed that students benefited from multiple opportunities to explore, engage, elaborate and re-represent ongoing understandings in the same and different representations. Greeno and Hall (1997) argued that different forms of representation supported contrasting understanding of topics, and that students needed to explore the advantages and limitations of particular representations. These studies also indicated that representations in science classrooms can serve many different purposes. As noted by Cox (1999) argued that representations can be used as tools for many different forms of reasoning such as for initial, speculative thinking, to record observations, to show a sequence or process in time (Ainsworth, Prain & Tytler 2011), to sort information, or predict outcomes. Students need to learn how to select appropriate representations for addressing particular needs, and be able to judge their effectiveness in achieving particular purposes.

Thus, the literature informing our practice has emphasised the centrality of representations in learning and knowing science, the need to frame learning sequences around the development of students' representational resources, the need to make explicit the form and function of representations, and the need to develop meta-representational competence. Further, we have drawn on a literature that goes further than emphasising representational interpretation, to advocate representational construction, negotiation and evaluation in authentic settings, in order to more deeply engage students in the knowledge building practices of science. Prior to the RiLS project, members of the team had explored these principles in classroom settings (Carolan, Prain & Waldrip 2008; Waldrip, Carolan & Prain 2010) and become convinced of their potential to engage students in quality learning. RiLS provided an opportunity to explore more systematically the nature of the teaching and learning principles that might be built around representation construction, and the resulting quality of student engagement with learning. The RiLS project had a number of facets, but the central feature upon which this book and this chapter are based was an in depth exploration in which members of the team worked closely with two primary, and two or sometimes three secondary teachers, to explore the approach applied to key science topics that were known to present learning challenges for students. These topics generally consisted of 6-12 lessons.

The research methods

Our work involved working closely with teachers to jointly construct units of work around key science topics known to present learning difficulties, and developing our insights over three topics in each of the primary and secondary classrooms, over three years. The primary school topics were animals in the school ground, energy, and water (changes to matter). The secondary school topics were force and motion, molecular models of substance, and astronomy. Our perspective is that the conceptual challenges in these topics, identified in the conceptual change literature, are fundamentally representational challenges (Tytler & Prain 2010). The teaching and learning approach we pursued with the teachers involved constructing learning sequences around a series of representational challenges that allowed assessment of representational adequacy and negotiation, and explicit consideration of the role of representations in learning and knowing. We chose to work with teachers across the middle years (5-9) of schooling, which are recognized as posing particular challenges for student engagement (Luke et al. 2003), and over which interest in science has been demonstrated to markedly decline (Tytler & Osborne, in press). The pedagogy in fact is consistent with middle years principles of active engagement and challenge in learning activities, entailing higher order thinking and reasoning. The aim of the research was to

a. iteratively develop over these three years a set of principles of teaching and learning that exemplified our ‘representation construction’ position,
b. better understand how this might look in practice,
c. investigate the challenges for teachers in adopting this approach, and
d. more sharply identify the student learning gains associated with the approach.

For each unit of work, the teachers’ practices, student-teacher interactions, and student activity and discussion were monitored using classroom video capture. This involved two cameras arranged to film the teacher, and a selected group of students for each lesson. Radio microphones were used for teachers and the student group. The video was captured on digital tape and uploaded and compressed, and coded to identify ‘quality teaching and learning moments’ for later analysis, using Studiocode software. These teaching and learning sequences were then selectively transcribed and subjected to interpretive analysis to identify the extent to which and in what ways the teaching and learning principles were exemplified, and for evidence of the ways in which the focus on representations supported reasoning and learning. Students were interviewed about their learning and their understandings of the nature of representations in constructing explanations, and teachers about their perceptions of the effectiveness of aspects of the sequence. Student workbooks were collected to provide a continuous record of presentational work.

In working with the teachers over three years, we developed a set of teaching and learning principles based on our experience in this and previous projects and on theoretical ideas described above. These were available to teachers, and were the working principles we used in helping teachers plan the lesson sequence. They reflect a view of quality learning as induction into the epistemic practices of the science community, with student construction of scientific representations understood as a crucial strategy for acquiring an understanding of the literacies of science as well as their underpinning epistemologies and purposes. The pedagogy is strongly aligned with notions of guided inquiry, pragmatism, and semiotics.

The set of teaching and learning principles described in this chapter were hence developed in a hermeneutic cycle involving a conversation between the research literature, the unfolding experience of the researchers in working with teachers and gathering multi-perspectival information on teacher and student learning experiences, a series of workshops in which teachers and researchers reflected on and discussed their observations and experiences, and analysis of a comprehensive data set including the video record of classroom interactions, student artefacts, teacher and student interviews, and student pre- and post-tests. While the broad principles were in place early in the project, the refinement represented here represents a growing understanding of the key elements and their relative emphasis, the relation between the different principles, and the detailed nature of the teaching practice and the student learning that attaches to each principle.

The principles of this representation construction approach to teaching and learning are first described in brief, before being illustrated in some detail. As part of this exemplification, we will present examples of the challenges faced by teachers in adopting the approach, and illustrations of the quality of student learning associated with the principle. Finally, we will argue that this approach is a particular form of guided inquiry that shows promise of resolving the tension in science education (Osborne 2006) between the need to introduce students to the established, canonical forms of science, and the need to engage them in the creative processes by which scientists explore phenomena and build new knowledge.

A representation construction approach to teaching and learning in science

The following principles were developed by the RiLS team, based on an iterative process of analysis of jointly constructed teaching sequences and discussion involving the researchers and teachers. The principles will be exemplified further below, drawing particularly on two of the secondary sequences; force and motion, and substances.

In a representation construction approach to teaching and learning:

1. *Teaching sequences are based on sequences of representational challenges which involve students constructing representations to actively explore and make claims about phenomena*
    a. *Teachers clarify the representational resources underpinning key concepts*: Teachers need to clearly identify big ideas, key concepts and their representations, at the planning stage of a topic in order to guide refinement of representational work.
    b. *A representational need is established:* Students are supported, through exploration, to identify the problematic nature of phenomena and the need for explanatory representation, before the introduction of canonical forms.
    c. *Students are supported to coordinate representations:* Students are challenged and supported to coordinate representations across modes to develop explanations and solve problems.
    d. *There is a process of alignment of student constructed and canonical representations:* There is interplay between teacher-introduced and student-constructed representations where students are challenged and supported to refine, extend and coordinate their understandings.
2. *Representations are explicitly discussed:* The teacher plays multiple roles, scaffolding the discussion to critique and support student representation construction in a shared classroom process.
    a. *The selective purpose of any representation:* Students need to understand that multiple representations are needed to work with aspects of a concept.
    b. *Group agreement on generative representations*: Students critique representations to aim at a resolution, in a guided process.
    c. *Form and function:* There is explicit focus on representational function and form, with timely clarification of parts and their purposes.
    d. *The adequacy of representations:* Students and teachers engage in a process of ongoing assessment of student representations.
3. *Meaningful learning involves representational/perceptual mapping:* Students experience strong perceptual/experiential contexts, encouraging constant two-way mapping/reasoning between objects and representations.
4. *Formative and summative assessment is ongoing*: Students and teachers focus on the adequacy, and coordination of representations.

These principles clearly involve a learning process for teachers as well as students. The clarification of the relation between concepts and representational resources, and the epistemological shift entailed in moving from a view of science knowledge as consisting of resolved, declarative concepts to one in which knowledge is seen as contingent and expressed through representational use, both involve significant challenges. For students who see knowledge as established facts and processes to be memorized, these principles offer no comfort. In the remaining part of this paper/chapter we will explore what these principles look like on the ground, drawing on two different topics, and the experience of teachers and students in developing this approach.

For each principle, we will examine the experience of teachers and students and the associated learning outcomes. For this we will draw particularly on the teaching and learning sequences in force and motion, and substances, both of which involved students in Year 8 (13 year olds).

Introducing representations of force

The first illustrative case is the planning and initial sequence of the forces unit. This was the first unit planned with the secondary teachers. Previous work (Waldrip, Carolan & Prain 2010) had shown that adopting a representational focus places stringent demands on clarifying what knowledge is to be pursued. The planning process began with discussion of key concepts associated with force. An examination of the chapter of 'forces' in the student textbook, which had been traditionally used to structure this unit, showed a 'run through' of many different types of force – contact forces, gravity, electrostatic and magnetic force – represented by arrows superimposed on complex and often dramatic photographs of force phenomena. In the book the use of arrows was not justified, but assumed, and the rules relating to the arrow convention were not discussed despite the complexity of some of the force diagrams.

In order to refine the representational work, the research team collaborated with the teachers in identifying the big ideas, or key concepts, of force. Students' alternative conceptions reported in the literature were discussed, including confusion between force and movement in diagrams, conceptions of force as embedded within a body's motion, and confusions about the force-acceleration relations in two dimensional motion, for instance applying to orbiting satellites. The force arrow convention was felt to be central to the representational conventions associated with problem solving in this area. The initial lessons in the sequence focused on the explorations of representations and learning of the scientific conventions of representing forces. As we have described elsewhere (Hubber, Tytler & Haslam 2010), the idea that force arrows are a negotiable convention, capable of flexible use, and that there is no absolute 'right' or 'wrong' convention to describe force, was an empowering realisation for these teachers. They were surprised that such an apparently resolved representation could be the subject of discussion. Thus, Principle 1a, concerning the identification of key ideas and the associated representational resources, involved in this case an epistemological shift for the teachers, who needed support to think their way into the approach.

Lyn's sequence was broadly representative of the approach of all three teachers, who met regularly to share ideas and experiences and plan. The sequence consisted of a series of challenges (Principle 1) in which students constructed representations to clarify force and motion processes, develop explanations, or solve problems. These were often reported on in the public space of the classroom, providing an opportunity for Lyn to question and negotiate the adequacy of the representations and move students towards an appreciation of canonical forms (Principles 1b and 1c). Lyn began the sequence by developing in students an understanding of the term 'force', assisting them to construct meaning for force through their everyday language. She did this by initially eliciting from the students' everyday action words they used, given the task of changing the shape of a lump of plasticine. A brainstormed list of words was quickly constructed and displayed on the board, including *stretch, carve, twist, roll, squeeze, mould* and *poke*. From the initial brainstorm listing Lyn re-represented the list into a tabular form after discussing with the students whether each of the elicited words could be placed into a column labelled 'push' or a column labelled 'pull'. She then introduced the scientific meaning of a force as a push or pull of one object onto another.

Lyn used gestures to re-represent the words as they were given by the students. Many of the students also provided a gesture explicating their uttered word. A noticeable feature of the teachers' and students' communication during this unit, that gestures became an important part of describing and validating what was being represented in words or diagrams. Gestures were used to indicate pushes or pulls or lifting forces, to mime the size of forces, and to indicate direction, and points of application of forces. We see this as a natural form of re-representation in which meaning is established in the public space by a process of representational weaving, in this case between verbal and gestural modes.

Lyn then explored with the students various ways in which an everyday action or series of actions involving forces could be represented in a two dimensional form on paper. The students were given the one minute task of changing the shape of a handful sized lump of plasticine, and following this task, they were to represent their actions in changing the shape of the plasticine in paper form. The different representations constructed by the students, some of which are shown in Figure 1, were discussed and evaluated within a whole class discussion.

Student 1 Student 2

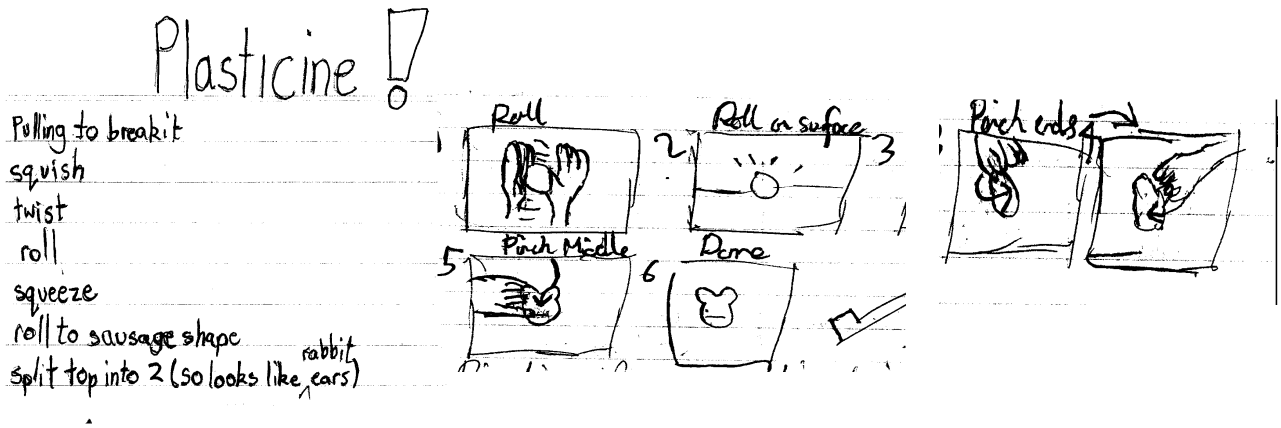


Fig. 1 Student representations of manipulating plasticine

One representation which had a sequenced series of figures with annotation (Figure 2 Image A) was unanimously accepted as providing clarity of explanation of the actions that were undertaken:

> *Lyn: Which one of these representations worked well in explaining what was done?*

Student 1: John's because it should you exactly what to do. Mine could have ended up anything.

Student 2: It was more visual, you can actually see it is easier to actually see what you did. With the other ones you could make it in different ways.

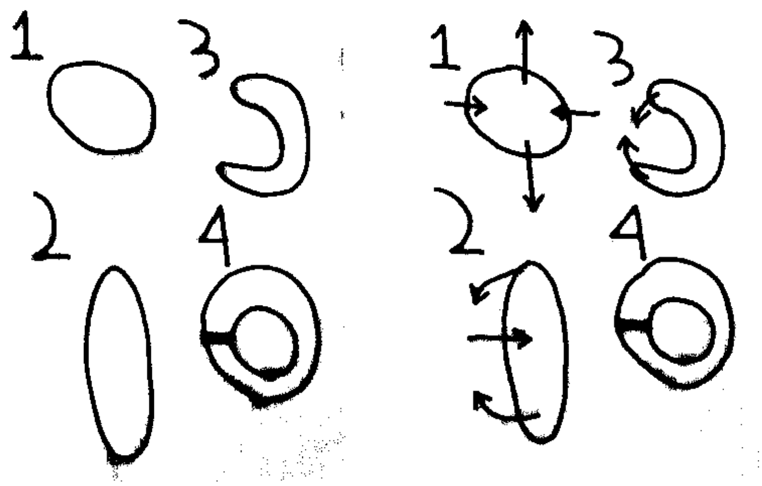


Image A Image B

Fig. 2 Reproduction of video images of John's representations

For the next stage of the sequence Lyn introduced diagrams using the scientific convention of representing forces as arrows. She discussed with the students the benefits in adding arrows, to represent pushes and pulls, to John's drawings to enhance the explanations (Figure 2 Image B). The students were then given the task of re-representing their explanations of changing the shape of the plasticine in pictorial form using arrows. Figure 3 shows three students' responses.

Student 1 Student 2 Student 3

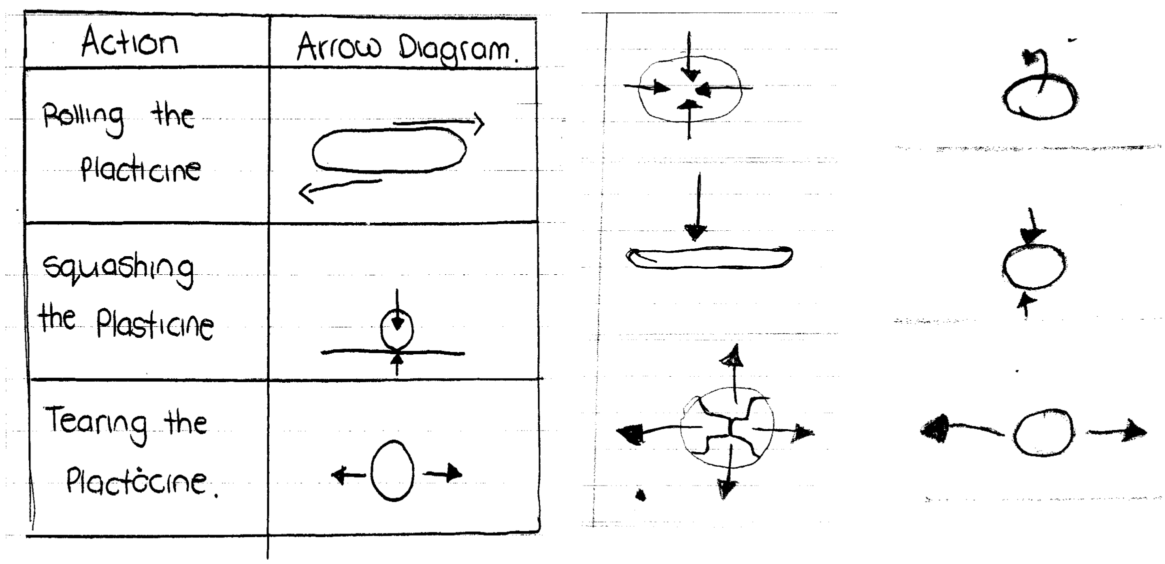


Fig. 3 Students' use of arrows

The completion of this task produced different meanings of the use of arrows, which Lyn discussed with her students. Several issues were raised and discussed including:

- Distinguishing between the arrow representation as a force or as a direction of motion;
- Distinguishing between different types of arrows, such as curved or straight, thick or thin, many or few.

Lyn then introduced the scientific convention of representing forces as straight arrows, when the base of the arrow is the application point of the force and the length of the arrow gives an indication of the strength of the force. The students were then encouraged to apply this convention to various everyday situations where forces are applied. For example, students were each given an empty soft-drink bottle and asked to represent the forces needed to twist off the bottle cap, and asked to use the arrow convention to represent a gentle, and a rough stretch (Figure 4).

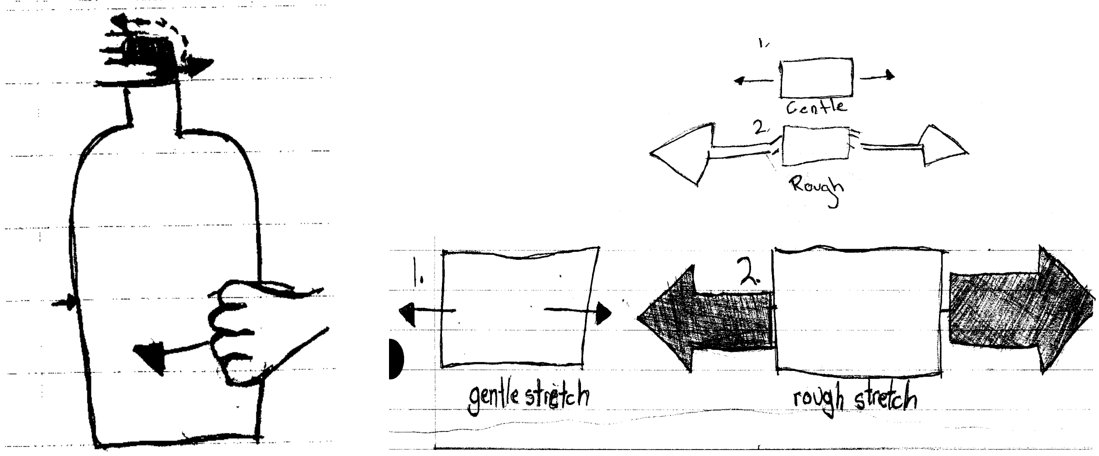


Fig. 4 Student exploration of the arrow representation of force

This introductory sequence is illustrative of a number of the representation construction principles, particularly how activity sequences are built that involve students constructing rather than practising and interpreting representations (Principle 1). The representation construction task is built on a need to communicate a sequence of shaping forces (Principle 1b), using verbal and visual and gestural modes (Principle 1c) and leads to the canonical arrow form through a process of explicit discussion of representational form and function (is it clear? Could we reproduce the sequence?) and of the adequacy of student representations (Principles 2, 2c, 2d). This process of public negotiation in which students agree on effective representations of the shaping process (Principle 2b), leads to an alignment of student and canonical representations (Principle 1d). The teacher, at particular points, introduced arrow notations in response to a felt representational need.

The approach could be seen as a particular form of guided inquiry in which teachers introduce tasks that open up representational needs, and intervene strategically to scaffold students' development of representational resources. It also has much in common with conceptual change approaches, with exploration of prior learning, and the development of explanation through exploration and guided discussion. In this particular version however, there is a close focus on representational resources rather than on rather more nebulous concepts, and there is ample scope for students to be generative and creative within the structured sequence. The end point is not fixed, with students free to produce different versions of the canonical forms.

Concepts about gravity, weight and mass formed the focus of the next stage in the teaching sequence. Students' ideas about these concepts were elicited through a questionnaire, and the responses helped shape the sequence. Several modes of representations formed the structure of the challenge activities. These included:

- Role-plays with a Swiss ball representing Earth and a soccer ball representing the Moon, and a toy bear simulating the gravitational effects on a person on earth, and on the Moon.
- Comparing everyday language conventions for the term 'weight' with the term's scientific meaning.
- The use of force and mass measurers to measure the mass and weight of common classroom objects, tabulating the results and determining the mathematical relationship between mass and weight of an object on the Earth's surface.
- A student-constructed spring force measurer and construction of a graph that connects the extension of the spring to the weight of an object.

Unlike a conceptual change approach, in which activities are designed to directly and rationally challenge 'alternative conceptions', this approach treats understanding as the capacity to utilise the representational conventions of science in thinking and communicating phenomena, and hence focuses on building up the representational resources of students, and their understanding of the role of representation in learning and knowing.

The next stage of the teaching sequence focused on the motion of objects and the effects of friction. Students were asked to imagine, on a magnified scale, the surface of an object as it slides along a flat surface (Figure 5). The students were asked to design, conduct an experiment and write a report on an investigation on factors that affect friction on everyday objects, like sports shoes. Within the investigation reports the students were encouraged to apply multiple representational modes. The audience for the report was someone like a friend who lived in another state and who could repeat the investigation.

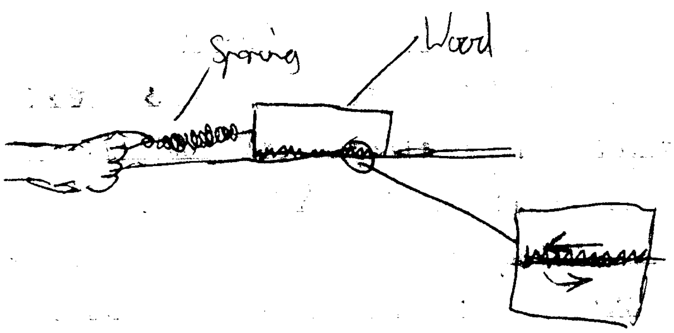


Fig. 5 Representation of friction

Friction is thus understood through the coordination of modes (Principle 1c), including arrow representations, detailed microscopic mechanisms, and gestures, aligned with and explanatory of tactile perceptual experiences (Principle 3). Each of these provides a selective, partial view of the phenomenon of friction (referred to in Principle 2a).

There were examples in the sequence where the challenge for students to visually represent enabled a public process of negotiation with the representations mediating a productive exchange. Sally established with the students that when an object is moving on a surface there will be friction that opposes motion and then asked:

> *Sally: Can you think of an example of why it might not be true?*
>
> *Student 3: On a skateboard.*
>
> *Sally: Can you draw it for me? I want to see how you think?*
>
> *Students 3: [Student drew a pair of wheels] the wheels will be turning that way [indicating by gesture and curved arrows on the wheels]*
>
> *Sally: if the wheels are moving that way in what direction is the skateboard moving?*
>
> *Student 3: [Student looks at his diagram, traces out the direction of the wheels and then indicated the direction of the skateboard with a straight arrow] that way? The wheels would be rolling and nothing will be pulling on them.*
>
> *Sally: So is there any force preventing it from moving?*
>
> *Student 3: No, the surface is already moving [Student represented by gesture the rolling motion of the surface of the wheel against the ground]*
>
> *Sally: Let's say you are on the skateboard [Sally modifies the diagram to include a representation of the student] and you are wanting to go in that direction but the skateboard is originally stationary.*
>
> *Student 3: [looking at the diagram] Oh. Well, your foot would do the pushing for you.*

The challenge 'can you draw it for me', or 'can you represent that' became increasingly common for teachers in this study, and accepted and responded to by students. This exchange between Sally and the student led to a classroom discussion regarding the reduction of frictional forces related to the nature of sliding surfaces and their area of contact. Different frictional effects where modelled with different orientations of the set of interlocked hair brushes that had acted as a model of the surface contact.

A bridging analogy (Clement, 1993) was used by Lyn to introduce the idea of contact forces. Figure 6 shows two students' interpretation of that discussion. In classical conceptual change theory, these bridging analogies are seen as props that help span the gap between naïve and scientific conceptions. From a representation construction perspective they are representational resources that are made available to students, that help them to coordinate meaning across different aspects of the phenomenon. Each representation offers a selective, partial perspective, and understanding involves the flexible coordination of a view that looks at macroscopic force effects and one that looks at their microscopic causes or correlates. This coordination of the macroscopic and microscopic is a challenge of much interest to researchers currently (Gilbert 2005).

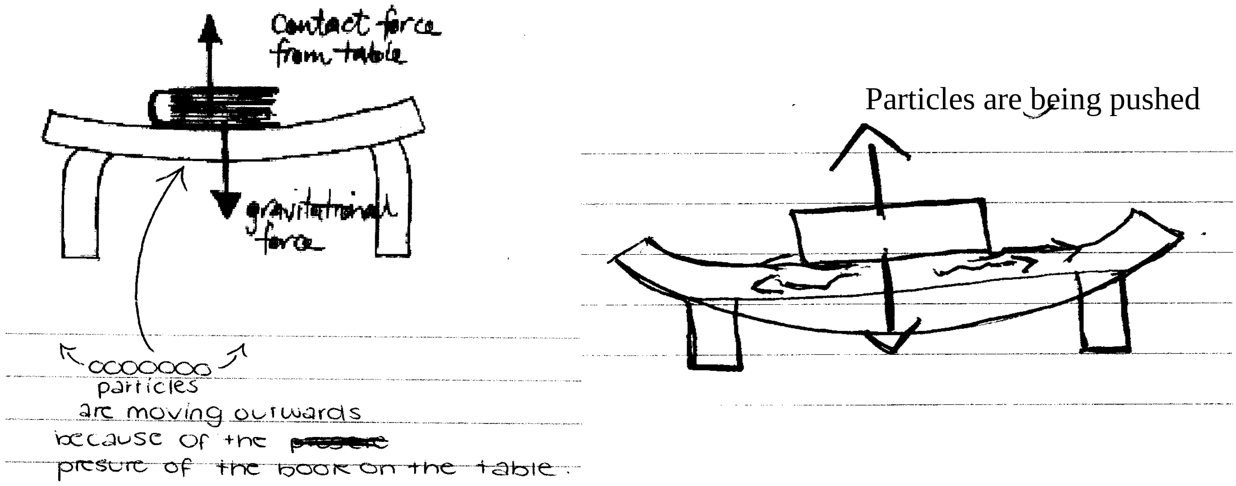


Fig. 6 Student representation of contact forces

A substances unit for Year 8

The research team also worked with a relatively inexperienced biology – chemistry trained teacher, Lauren, on a related year 7 10-lesson unit introducing the particle model and coordinating this with states and properties of matter.

In both sets of sequences student representation construction was a central feature. In an exercise involving the categorization of different substances in the year 7 sequence, class discussion on the lack of clarity of the distinction led to students suggesting a Venn diagram representation that admitted cross-over categories of solids, liquids and gases. The teacher also discussed a ‘continuum representation’ which students engaged with. The resulting board work is shown in Figure 7

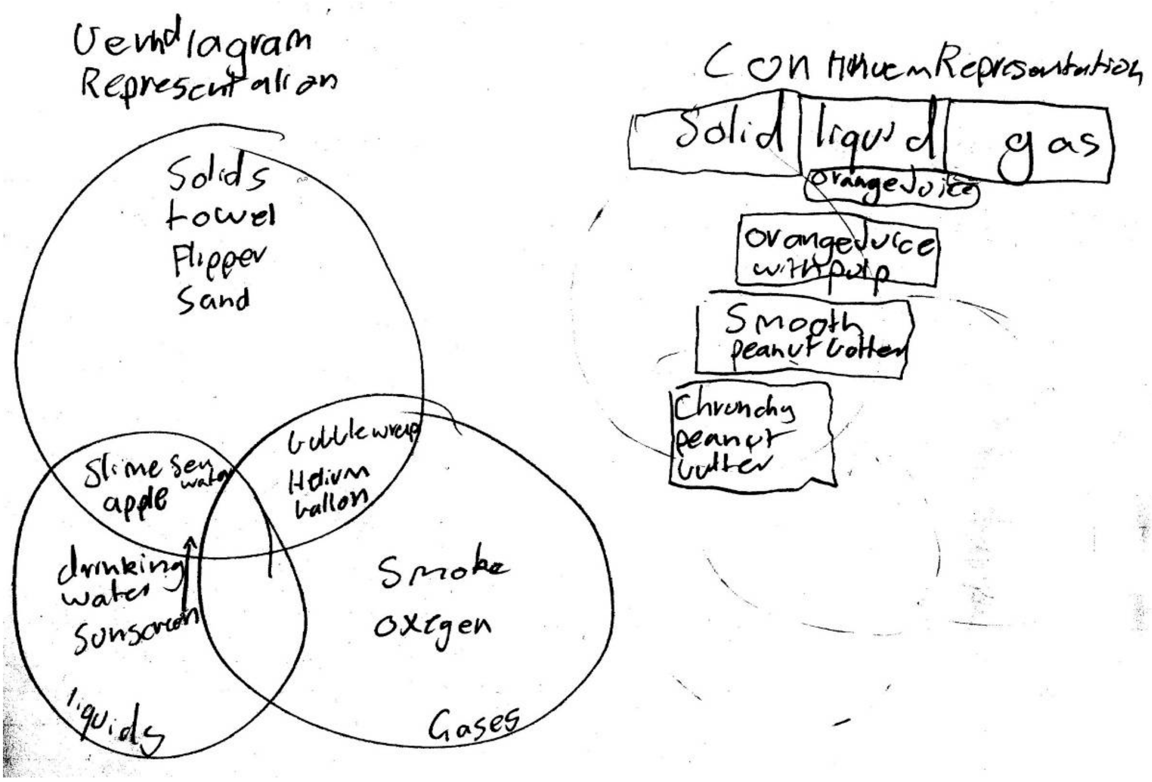


Figure 7: Representations of materials as combinations of solid, liquid and gas

Here, as with the forces unit, one can see the response of students to a representational need and the richness of discussion in the public space of the classroom. The agency granted to students is also apparent. The limitations of the representation were also acknowledged, when a student asked where bubble wrap should be put, and the teacher responded: “in this case this is where the representation doesn’t fit?”

In a sequence of representational challenges intended to move students to an alignment of particle ideas with macroscopic properties of materials, students drew what they imagined particle arrangements to explain the property. Figure 8 shows the basic worksheet challenge for the property of paper holding its shape, and three student responses, drawn on the board, which were discussed for their adequacy. The instructions were to draw a representation using Particle ideas, which only needs to explain the property that is being described. For the first challenge the three responses are all adequate since they allow breaking up of the structure. For the second challenge the first response is inadequate since it has no structure to sustain shape.

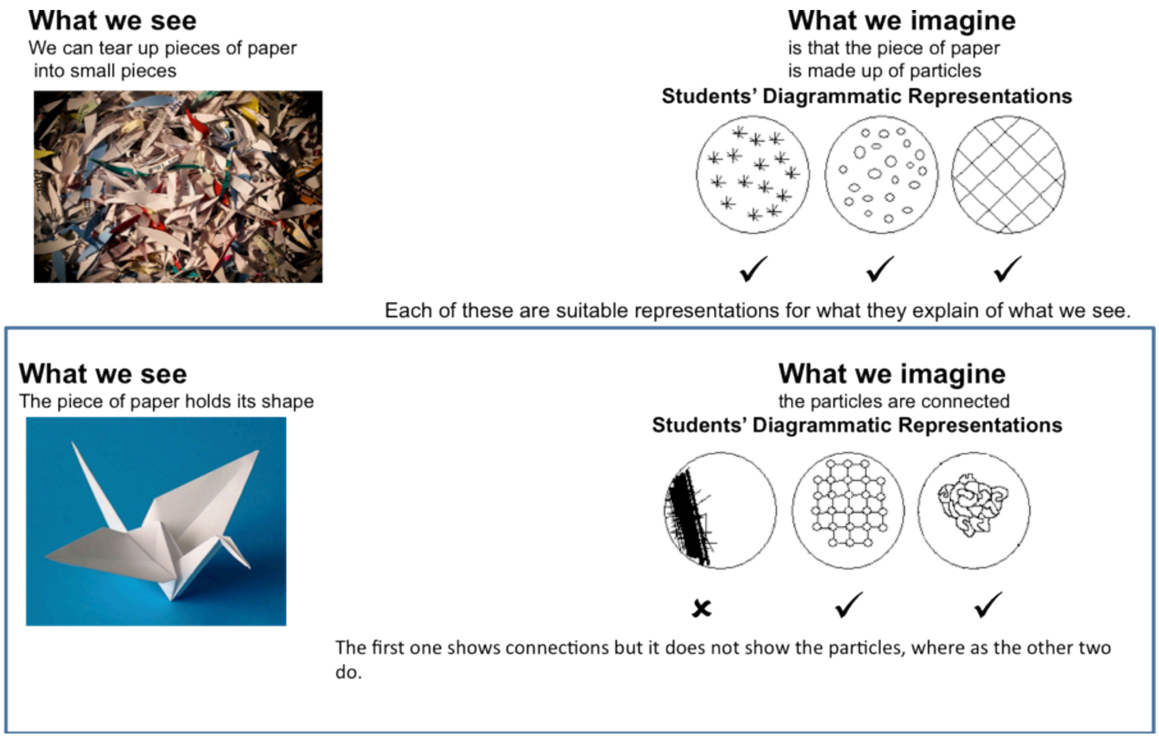


Figure 8: Student drawings of 'what we imagine' to explain properties of matter.

In groups students were given a stick of chalk, lump of plasticine and a plastic spoon, and challenged to draw a super magnified view of a sample of the substance that makes up each object to show a particular physical property of the object. The particular property was their choice and so they needed to annotate their representation to explain this. Note that the idea that representations are selective in their intent, and partial, is embedded in the nature of this challenge (Principle 2a). The representational/ perceptual mapping (Principle 3) is very clear here also. Figure 9 shows responses to challenges to 'imagine' particles that explain the stretchiness of a rubber band.

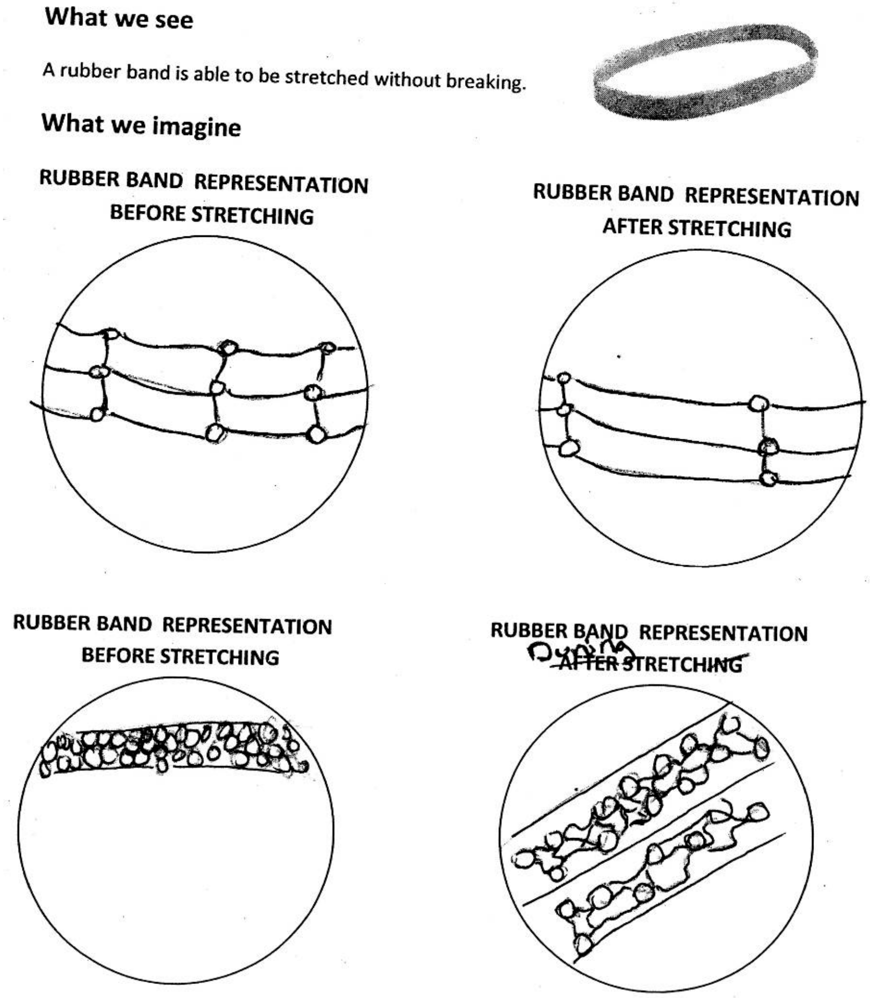
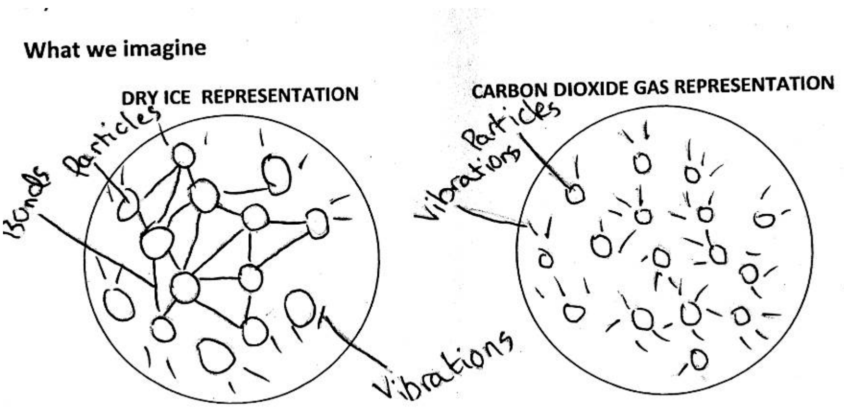


Figure 9: Representing particle arrangements for a rubber band

Figure 10 shows two responses to a challenge to represent dry ice sublimating. The responses in these figures demonstrate the variation and the quality of student work, and the lively engagement of students with the task.



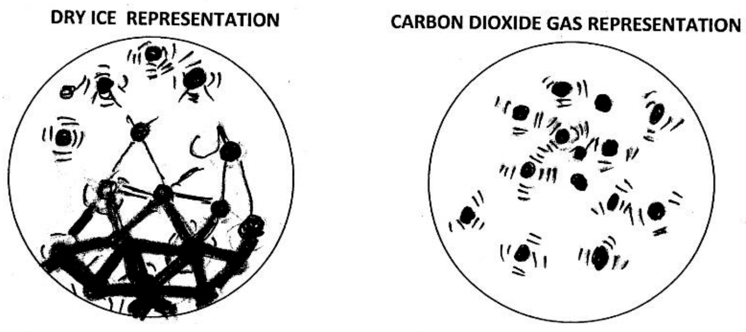


Figure 10: Representing dry ice and carbon dioxide using particle ideas

These tasks, as for the force sequence involving public discussion of the adequacy of representations, provide insight into student thinking such that formative assessment is embedded naturally into the teaching and learning process. The process of negotiation of representations and alignment with canonical representations requires teachers to constantly monitor student products. In the dry ice example of Figure 10 for instance, important features at issue are the breaking of bonds in sublimation, and the increase in inter- particle distance and particle movement. As Lauren said:

> *There was more class discussion in this teaching sequence as there were a lot of open-ended questions set out to the students. I wanted to hear the majority of the class' thoughts before moving on to a new stage in the sequence. They all felt a part of the group if they got to share what they thought (Lauren, interview)*
>
> ***Researcher:*** *You often had students evaluating each other's representations.*
>
> ***Teacher:*** *To open up different ideas. This gave insight into their thinking and how they interpreted my teaching so this gave constant feedback on their understandings*
>
> *...what you're seeing with representation is that you're seeing what's in their brain, not what they're regurgitating. (Lyn)*

The question of assessment will be taken up in more detail in another paper. Over the project, there were two innovations in summative assessment developed by the team. One was that items encouraging or requiring students to represent multi-representationally and multi-modally, were included in tests. This might simply involve a change in language from 'explain' to 'represent to explain', with the provision of space and the absence of lines. These items however pose difficulties in interpreting reliably the extent of understanding. The other was that items were developed that explicitly tested students' meta-representational competence. Figure 11 is an example of one such item focusing on students' understanding of the selective and partial nature of models.

1. a. On the right is a picture of a section of a jigsaw.
What features of the jigsaw help us to explain the features
of a sample of a substance in a solid state? (2 mks)

This helps us explain that particles hold on ~~top~~ each other. It also shows that the particles can't move past each other, like in a liquid or gas state.

2

b. What features of a jigsaw don't help explain the features of a sample of a substance in a solid state? (2 mks)

~~The jigsaw helps~~ The jigsaw model doesn't show that particles vibrate and particles have kinetic energy. It also doesn't show that particles in a sample are all the same shape, size and colour.

2

Figure 11: Summative assessment item focusing on meta representational competence

Impact of the approach on student learning

In taking a conceptual focus to topic planning the teachers saw themselves as being able to move away from the textbook framing their pedagogical approach. This meant less coverage of content, but provided a more purposeful and a deeper approach to learning. Lyn commented:

> *Before we crammed it all in and didn't know what to cut out…we were so pleased to actually pause, particularly in that Forces unit, which was so superficial and done so badly according to the textbook that we were using. We were so pleased to go into depth. And it was so lovely to be able to develop ideas with the kids. (Lyn, focus group)*

The explicit focus on representations were seen by the teachers as providing a solid grounding for ongoing conceptual work.

> *The thing I like about using arrows, I felt I was now coming from a base level whereas before when I taught forces, in hindsight, I now realise I was sort of coming in via the second and third floor. By slowing it down, and giving the kids a slower pace, and getting them on board to use the arrows, and thinking about the directions and size, it sets up the rest of the unit and gives them a really good structure to the concept. So that they can actually start to think in terms of something that is quite concrete for them. (Lyn, focus group)*

> *When we did use the previous unit plan, I noticed that it was very text book based plus it seemed to pack 'every' topic available into the unit. With a big unit, it was hard to spend the appropriate amount of time teaching the topic. I noticed this year that we were able to choose a couple of topics that blended together well and use the time available to really connect with the students. (Lauren, interview)*

The teachers were clear that there was more discussion, and deeper learning than had occurred previously in the text book framed units. In reflecting on the impact on student learning the teachers saw benefit in students having the authority to construct their own representations to explain their reasoning.

> *Lyn: … what the representation's done is it's changed the conversation from "what" to "how", and therefore they're more doing than thinking and talking.*
>
> *Sally: .. for me it's changed from "what's happening", to "how would you represent that?" And therefore the students are internalising it and showing it.*
>
> *Lyn: … it's a very powerful way of showing understanding and getting the kids to think … it allows kids to be creative in showing their understanding with different representations. And we can all see different ways of doing it.*

The quality of student work found in the student artefacts above attests to the learning that took place in these units. Pre and post test comparisons have shown substantial growth in understanding. Table 1 shows the improvement in correct responses from pre- to post- test on the multiple choice items in the test.

In this and an astronomy unit a measure of the improvement in student knowledge over the teaching sequence has been attempted, using a 'normalised gain index', <g>, previously used in other studies using identical multiple choice pre- and post-tests (Hubber 2010). <g> is the ratio of the actual average student gain to the maximum possible average gain: <g> = (post% - pre%) / (100 - pre %), reported by Zeilik, Schau, & Mattern (1999). Gain index values can range from 0 (no gain achieved) to 1 (all possible gain achieved). A respectable mean gain is argued to be 0.3 (Kalkan & Kiroglu, 2007, p. 17). In contrast the mean gain for the 'substances' tests was 0.78, on questions that represented conceptions identified in the literature as problematic. A similarly impressive result was found for astronomy, for which it was possible to compare gains on identical items used in previous research led studies.

Thus, there is evidence from teachers, from the video and student artefact data, and from pre- and post-tests, that the representation construction approach yields significant learning gains.

7. Each statement tick the box you feel most fits your understanding of the statement.	**% correct response**		**Normalised gain index**
Statement	**Pre-test**	**Post-test**	**<g>**
All objects consist of very tiny particles called atoms.	78	90	0.54
A molecule is a tiny particle that consist of more than one atom bonded to each other.	64	90	0.72
When a substance freezes the temperature must always be less than 0 °C.	52	91	0.81
It is possible to heat an object to +1000 °C but it is **not** possible to cool it -1000 °C.	40	93	0.88
When wax melts the molecules that make up the wax change from being hard and firm to being soft and 'gooey'.	11	68	0.64
When a substance condenses it changes from a gas into a liquid.	71	88	0.59
A closed bottle with small amount of water at the bottom is left in the sun. After awhile, when the water has evaporated, the mass of the bottle is now **less** than before.	48	98	0.96
The molecules inside liquids and gases are moving but in solids they are stationary.	19	98	0.98
In the spaces between atoms of an object there is air.	38	93	0.89

Table 1: Pre- and post- test learning gains for multiple-choice items, in the Year 7 substances unit

The representation construction principles developed in this study have a dual character; as pedagogical principles and as statements about the conditions for quality learning in science. They represent in fact both teacher and student learning, because of the demands of the construction, evaluation and negotiation of representations. Teachers have told us of the clarity they experienced through the process of planning around key concepts and representations, and about the challenge of deeper conversations about the use of these tools to explain or solve problems in science. They talk of greater student engagement with science ideas, a finding that has been explored theoretically by Prain and Tytler (submitted), drawing on semiotic, epistemological and epistemic justifications for this representation construction practice.

Teachers and students, through this project, grew in their meta-representational understandings, as one might expect from an emphasis on Principle 2, the explicit discussion of representations.

Sometimes the representation will help us to get to that knowledge. So it is a continuous feed-back; as Sally said, if we try to understand the concepts we have to go to various types of representations …Representations help us get the knowledge, we use the knowledge to help to build our representations (Lyn, focus group)

Teachers increasingly focused on the selective and partial nature of models, and developed in epistemological sophistication of their views. Students were challenged in the substance unit in particular, to evaluate different particle representations, for instance the analogy of popping corn for evaporation (‘What’s good about the model? What’s bad about the model?’ As Lyn explained:

… we’re not teaching the particle model as in, this is the model and see how it relates to real life. It’s more, this is real life and we have a model and does it actually explain real life, and does it explain this and that? And particularly … how good is the representation?

Sally emphasised how students had adopted a critical perspective on models to the extent that in the following year it was noticeable that they took a critical stance to their text book representations. The relation of models and representations to knowledge was probed in interview. The following exchange was between a researcher and a year 8 student:

R: *You have two separate words, one is Understanding and the other one is Representations. [R & U were drawn on the page –Figure 12] how do they connect?*

S: *Through many representations you can come to an understanding [drawing arrows from R to U]. So many representations help you get an understanding*

R: *So do you use representations to show your understanding?*

S: *Representations help you understand but then [now drawing arrows from U to R] through your understanding you can give many representations. So it works both ways.*

Figure 12: Understanding and representation

Another student was asked, “Do you need more than one type of representation to understand? She responded:

I think you need more than one [representation]. Some things get explained better in different ways. Like something just looks better. You can understand more when there are graphs in it. Like other things like diagrams need to have arrows rather than writing to show what happened. Some things need just writing because they are very complicated. You just need to explain them and some things need all of them.

Conclusion

Through a three year process of working with teachers to develop and refine the representation construction approach, analyzing video and student artefacts and interview data, and discussions within the research team and with the teachers, we have come to a clearer understanding of the core pedagogical underpinnings of the approach how these support and shape student learning in science.

The approach is a variant of guided inquiry and is consistent with aspects of conceptual change approaches. We believe however that the explicit focus on representation construction constitutes an innovation in science teaching and learning that can potentially resolve the well recognized contradiction in science education (Osborne 2006) between the need to represent in classroom processes the exploratory and imaginative aspects of science knowledge building practices, and at the same time introduce students to the canonical products of science (Klein 2010). This resolution comes about through the twin focus on representation as a process, and a product. Students in these units were engaged in imaginative production and negotiation of ideas, and achieved significant learning in key ideas as evidenced in their performance on traditional test items, as well as demonstrating capabilities in generating and coordinating representations, and in meta – representational competence.

The principles do not speak strongly to unit structure, but as the analysis shows can be exemplified even in short activity sequences. In a separate analysis, we will look at the structural features of the sequencing of ideas across key topics in primary and secondary schools, to identify patterns they have in common. However, it is clear that the approach admits of considerable variety in this respect.

The approach captured in the principles places significant demands on teachers and on students, and speaks to both student and teacher learning. As they planned and executed learning sequences, teachers were challenged to develop deeper understandings of key science ideas, and challenged pedagogically and epistemologically. They were, however, enthusiastic about the learning outcomes achieved by students and also by the pleasures of deeper engagement in classroom discussion with students and their developing ideas. For students it seemed that the enhanced engagement flowed from the active way in which ideas were introduced and negotiated and linked to science phenomena.

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