In this chapter we lay out the principles of an approach to teaching and learning science based on student generation, negotiation and refinement of representations in a guided inquiry process. We first tell the story of how we developed this perspective, building on Chapters 1 and 2, and the research approach that led to these principles. The principles of the representation construction approach are described, then exemplified using detailed analysis of parts of classroom learning sequences on force, and substances. We then give examples of teacher responses and beliefs, and finally provide evidence of student conceptual, and meta-representational learning, from this approach.

BACKGROUND TO THE TEACHING AND LEARNING APPROACH

Following the explorations of a pedagogy focused on representations described in chapter 2, a major focus of the Role of Representation in Learning Science (RILS) project was to explore more systematically and in more detail 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 & Waldrip, 2008), and further drawing on and interpreting a diverse literature concerning student knowledge construction and its relation to representation and modeling. This included the extensive 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.

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. Chapter 2 described the early exploration of these principles in classroom settings (Carolan, Prain & Waldrip, 2008; Waldrip, Carolan & Prain, 2010). Through this work we became convinced of their potential to engage students in quality learning. RILS provided an opportunity to explore more systematically the nature of an approach to teaching and learning that might be built around representation construction, and the resultant quality of student engagement with learning. The RILS project had a number of facets and collaborative work with teachers at multiple sites, but this chapter is based on an in depth exploration where members of the team worked closely with two primary, and three secondary teachers, to explore the approach applied to key science topics that were particularly 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 construct units of work jointly around key science topics known to present learning difficulties, developing 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 in nature (Tytler & Prain, 2010). The teaching and learning approach involved constructing learning sequences with the teachers around a series of representational challenges that foregrounded 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 difficulties for student engagement (Luke et al., 2003), and where interest in science has been demonstrated to markedly decline (Lindahl, 2007; Tytler & Osborne, 2012). The pedagogy 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:

• iteratively develop over these three years a set of principles of teaching and learning that exemplified our ‘representation construction’ position,
• understand better how this might look in practice,
• investigate the challenges for teachers in adopting this approach, and
• 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 (http://studiocodegroup.com/). 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 representational work.

In working with the teachers over three years, we developed a set of teaching and learning principles based on our unfolding experience and on theoretical ideas described above. These were available to teachers, and were the working principles we used to help 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 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 reflects 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 arising from 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 present examples of the challenges faced by teachers in adopting the approach, and illustrate the quality of student learning associated with the principle. Finally, we 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 principles underpinning the representation construction pedagogy 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.

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 entail a major shift in perspective. In the remaining part of this paper/chapter we 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.

Compared to the IFSO framework described in Chapter 3 these principles are more detailed and more consciously operationalize the representation construction approach. They are more layered in their treatment of the representation construction tasks, and the nature of judgment of representational adequacy. The changed emphasis reflects the comprehensive data set we generated in working with teachers to address the issues raised in the prior research.

Principles Underpinning a Representation Construction Approach to Teaching and Learning

1. **Teaching sequences are based on sequences of representational challenges:**
   Students construct 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.
The principles are exemplified below. For each principle, we examine the experience of teachers and students and the associated learning outcomes. For this we 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, and what will count as evidence of understanding. The planning process began with discussion of key concepts associated with force. An examination of the chapter of ‘forces’ in the student textbook, 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 focus of this representational work, the research team collaborated with the teachers to identify 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 thus 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 is 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. The terms push and pull operate here as an inter-language (Olander, 2010; Tytler et al., 2012), bridging the gap between everyday words and the formal scientific term.

Lyn used gestures to re-represent the words as they were given by the students. Many of the students also provided a gesture to explicate their meaning further. A noticeable feature of the teachers’ and students’ communication during this unit was 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. These point to the embodied nature of the force concept. 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 3.1, were discussed and evaluated within a whole class discussion.

Figure 3.1. Student representations of manipulating plasticine.

One representation, which had a sequenced series of figures with annotation (Figure 3.2 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 showed 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.

Figure 3.2. 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 3.2 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 3.3 shows three students’ responses.

![Figure 3.3. Students’ use of arrows.](image)

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 3.4).

![Figure 3.4. Student exploration of the arrow representation of force.](image)
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 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 challenge ‘alternative conceptions’ and establish a scientific perspective through a rational evaluative process, this approach treats understanding as the capacity to utilise the representational conventions of science in thinking and communicating about phenomena, and hence focuses on building up students’ representational resources, 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 3.5). The students were asked to design, conduct an experiment and write a report on an investigation of 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.

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 were explored with different orientations of the set of interlocked hairbrushes 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 3.6 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 naive 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 currently a challenge of much interest to researchers (Gilbert 2005).

![Figure 3.6. Student representation of contact forces.](image)

**A Substances Unit for Year 8**

After the forces unit, Lyn and Sally were involved in a Year 8 substances unit with a focus on the coordination of molecular models and macroscopic properties of
materials. The topics covered atoms, molecules, elements, compounds and mixtures. The research team also worked with a relatively inexperienced biology – chemistry trained teacher, Therese, 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 categorisation 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 3.7.

![Figure 3.7. Representations of materials as combinations of solid, liquid and gas.](image)

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 imagined particle arrangements to explain the property. Figure 3.8 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 was judged inadequate since it has no structure to sustain shape.
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 3.9 shows responses to challenges to ‘imagine’ particles that explain the stretchiness of a rubber band.

Figure 3.10 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.

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 (Principle 4). 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 3.10 for instance, important features at issue are the breaking of bonds in sublimation, and the increase in inter- particle distance and particle movement. As Therese 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
They all felt a part of the group if they got to share what they thought (Therese, 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 Chapter 9. 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 (Principle 2). Figure 3.11 is an example of one such item focusing on students’ understanding of the selective and partial nature of models.

**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. (Therese, 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 3.1 shows the improvement in correct responses from pre- to post- test on the multiple choice items in the test.

Table 3.1. Pre- and post- test learning gains for multiple-choice items, in the Year 7 substances unit

<table>
<thead>
<tr>
<th>Statement</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>% correct response</th>
<th>Normalised gain index</th>
</tr>
</thead>
<tbody>
<tr>
<td>All objects consist of very tiny particles called atoms.</td>
<td>78</td>
<td>90</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>A molecule is a tiny particle that consist of more than one atom bonded to each other.</td>
<td>64</td>
<td>90</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>When a substance freezes the temperature must always be less than 0 °C.</td>
<td>52</td>
<td>91</td>
<td>0.81</td>
<td></td>
</tr>
<tr>
<td>It is possible to heat an object to +1000 °C but it is not possible to cool it -1000 °C.</td>
<td>40</td>
<td>93</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>When wax melts the molecules that make up the wax change from being hard and firm to being soft and 'gooey'.</td>
<td>11</td>
<td>68</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>When a substance condenses it changes from a gas into a liquid.</td>
<td>71</td>
<td>88</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td>48</td>
<td>98</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>The molecules inside liquids and gases are moving but in solids they are stationary.</td>
<td>19</td>
<td>98</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>In the spaces between atoms of an object there is air.</td>
<td>38</td>
<td>93</td>
<td>0.89</td>
<td></td>
</tr>
</tbody>
</table>

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 (Hubber, 2010). 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.

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 (2012), drawing on semiotic, epistemological and epistemic justifications for this representation construction practice. These ideas are described in Chapter 5.

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 feedback; 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 textbook 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 3.12] how do they connect?
A REPRESENTATION CONSTRUCTION APPROACH

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.

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 and 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