The Role of Representation in Teaching and Learning Ideas about Matter

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Abstract

The research described in this paper is designed around the notion that learning involves the recognition and development of students' representational resources. This paper describes a classroom sequence in Ideas about Matter that focuses on representations and their negotiation, and reports on the effectiveness of this perspective in guiding teaching, and in providing further insight into student learning. Classroom sequences involving two experienced teachers (2008, Year 8 students) and an inexperienced teacher (2010, Year 7 students) were videotaped using a combined focus on the teacher and groups of students. Video analysis software was used to code the variety of representations used teachers and students, and sequences of representational negotiation. The paper reports on the effect of this approach on teacher pedagogy and on student learning of Ideas about Matter. The paper will present data from video of classroom activities, students' work samples, student and teacher interviews and pre and post-unit testing, to explore what a representational focus might entail in teaching Ideas about Matter, and the role of representations in learning and reasoning and exploring scientific ideas.

Introduction

A large body of research in the conceptual change tradition has shown the difficulty of learning fundamental science concepts (Duit, 2002), yet conceptual change schemes have failed to convincingly demonstrate improvements in supporting significant student learning (Duit & Treagust, 1998; Limon, 2001). Recent work in cognitive science has challenged this purely conceptual view of learning, emphasising the role of language, and the importance of personal and contextual aspects of understanding science (Gee, 2004; Klein, 2006). These new perspectives put a very strong emphasis on the role of representation in learning, implying the need for learners to use their own representational, cultural and cognitive resources to engage with the subject-specific representational practices of science.

From these perspectives students need to understand and conceptually integrate different representational modalities or forms in learning science and reasoning in science (Ainsworth, 1999; Lemke, 2004). These researchers argue that to learn science effectively students must understand different representations of science concepts and processes, and be able to translate these into one another, as well as understand their co-ordinated use in representing scientific knowledge and explanation-building. Classification categories of representations are generally held to include textual, visual, mathematical, figurative and gestural, or kinaesthetic, understandings.

In encapsulating the key features of adopting a teaching sequence with a representational focus and the roles played by representations in supporting reasoning and learning we are collaborating with other colleagues[1] in developing a set of pedagogical principles based on experience in working with a range of teachers employing the role of representations in learning science. These principles draw on literature that emphasise the active role of representational work in supporting learning in science (Greeno & Hall, 1997; Ford & Forman, 2006). The following emerging pedagogical principles involve:

[1] This study is part of a wider research project titled, *The Role of Representation in Learning Science*, conducted at three university sites.

The pedagogical principles of this approach involve:

1. *Sequencing of representational challenges involving students generating representations to actively explore and make claims about phenomena*
   a. *Clarifying 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. *Establishing a representational need:* The sequence needs to involve explorations in which students identify the problematic nature of phenomena and the need for explanatory representation, before the introduction of the scientifically accepted forms.
   c. *Coordinating / aligning student generated and canonical representations:* There needs to be interplay between teacher-introduced and student-constructed representations where students are challenged and supported to refine and extend and coordinate their understandings.
2. *Explicitly discussing representations:* The teacher plays multiple roles, scaffolding the discussion to aim at student self assessment as a shared classroom process.
   a. *The selective purpose of any representation:* Students need to understand that a number of representations are needed for working with multiple aspects of a concept.
   b. *Group agreement on generative representations*: There needs to be a guided process whereby students critique representations to aim at a resolution
   c. *Form and function:* There needs to be an explicit focus on representational function and form, with timely clarification of parts and their purposes.
   d. *The adequacy of representations:* There needs to be ongoing assessment (by teachers and students) of student representations.
3. *Meaningful learning:* Providing strong perceptual/experiential contexts and attending to student engagement and interests through choice of task and encouraging student agency.
   a. *Perceptual context:* Activity sequences need to have a strong perceptual context (i.e. hands on, experiential) and allow constant two-way mapping between objects and representations.
   b. *Engagement / agency:* Activity sequences need to focus on engaging students in learning that is personally meaningful and challenging, through affording agency and attending to students' interests, values and aesthetic preferences, and personal histories.
4. *Assessment through representations:* Formative and summative assessment needs to allow opportunities for students to generate and interpret representations. Students need to be supported to extend and demonstrate learning through developing explanations that involve coordinating and re-representing multiple modes.

In this project we worked closely and collaboratively with Middle Years teachers to develop teaching sequences in key conceptual areas such as 'forces', 'astronomy', 'ideas about matter', 'energy' and 'animal adaptations'. In this work we developed and validated the pedagogical principles. This paper explores how teachers responded to the new approach, implied by the pedagogical principles above within the topic of 'ideas about matter'. The students' conceptions literature in this topic is quite extensive (Kind, 2004) highlighting the difficulties students have in understanding of this science domain. Three teachers were involved in teaching the topic. Two experienced teachers from the same secondary school taught the topic concurrently to Year 8 students in 2008. The third teacher was in her third year of teaching and taught the topic in another secondary school at the beginning of 2010.

Research Question

The research question was: What issues are raised with an explicit representational focus on the teaching and learning of ideas about matter?

Research Methods and Question

The researchers worked closely with two experienced teachers, Lyn and Sally[2], and an inexperienced teacher, Therese, to plan a teaching sequence that highlight representational issues in helping students explore and develop key conceptual understandings about ideas about matter. The planning sought to develop a model of classroom practice that foregrounds representational negotiation as a basis for conceptual growth. The teaching sequence lasted 14 lessons (2008) and 10 lessons (2010) varying between 45 minutes and 90 minutes of class time.

Teaching sequence

The features of the sequence were:

1. Pre-test of key ideas associated with the topics to be taught. The pre-test included true/false and multiple choice questions as well as short answer questions where students were to provide full explanations using text and/or drawings.
2. For the 2010 sequence the students' notebooks were different to their normal A4 lined notebooks but larger sized project type notebooks which, when opened out, had one line page on the left and an unlined page on the right. This encouraged the construction of multiple representations by the students.
3. Students were given representational challenges where they were to generate a representation with a particular purpose. For example,
    a. Draw a diagrammatic representation, using particle ideas, to explain the observation that when you pick up a piece of paper it holds its shape.
    b. Draw a representation that explains the ability of a rubber band to stretch without breaking.
4. There was explicit discussion of representations where students assessed the adequacy of their own representations in addition to the canonical forms.
5. Instances where representations where used in exploring properties of matter. For example,
    a. Animations showing the motion particles in different state;
    b. Role play of the dynamic systems heating;

    In most instances representations did not stand alone but were integrated with others. For example, gesture, everyday/science language and diagrams.
6. Inquiry-based investigations whereby student groups were to collect some data, represent it in a form of their choosing, analyse and interpret this data with the purpose of answering some questions. The students were to provide a written report as a summative assessment task and present their findings to the rest of the class in whatever form they chose. For example, investigating the viscosity of three different liquids.
7. A Predict Observe Explain (POE, Gunstone & White, 1992) activity whereby students predict compression of a syringe when full of air, liquid and solid.
8. Post-test that included the same set of multiple choice questions and true/fale questions given in the pre-test and also included some of the short answer questions. In addition, further short answer questions were given.

[2] Pseudonyms have been given to teachers in this study. Where reference has been made to names of students pseudonyms have also been used.

Data Collection

Data collected included: (1) video recordings of most classroom sessions and of student interviews; (2) student workbooks; (4) pre- and post-tests; (5) transcripts of tape recordings of teacher and student interviews and (6) researchers' field notes.

The video sequences used two cameras – one tracking the teacher and the main classroom interactions, and one focusing on a small group of students. The teacher and student group were radio miked. The student group's microphone was transported with the group if it moved around. Most lessons in the unit sequence were videotaped as many of the lessons had some part or parts that had a representational focus. The videotaped lessons were coded using 'studiocode' software which has been designed for this type of analysis, to allow quick reference to representational events and instances of classroom negotiation of representations. The analysis reported here involved triangulation between video data, transcripts of student and teacher interviews, student work, pre- and post-tests and researcher field notes.

Findings

Several issues arose in undertaking teaching sequences with a representational focus implied by the pedagogical principles described above. These issues related to pedagogy, epistemology, content coverage and assessment.

In planning for each of the topics the research team collaborated with the teachers in identifying big ideas or key concepts at the planning stage in order to guide the refinement of representational work. For example,

- All matter is composed of tiny indivisible particles too small to see even with the most powerful microscopes.
- The particles that make up the substances do not share the properties of the substance they make up.

For the 'ideas about matter' topic the 2008 teachers in past years had developed a two-week teaching sequence that extended on a previous year's topic on changes of state and particle model with the introduction of the concepts of atom, molecule, element, compound, mixture and pure substance. The teachers were somewhat surprised at the prevalence of alternative conceptions elicited by the students in the topic pre-test, particularly in areas covered in teaching the students the previous year. This prompted them to rethink the way they were teaching particle ideas about matter. The substances pre-test responses by the students indicated that whilst the majority of students understood the term atom and molecules they exhibited several alternative conceptions that included: *matter is not conserved in evaporation*; *the space between molecules is filled with air*; and *molecules have the properties of the bulk material they constitute*. The teachers realised that they had been teaching the particle theory as a body of knowledge itself and only loosely using it to explain macroscopic behaviour of matter. They now thought that the teaching approach needs to have constant movement between macroscopic behaviour of substance and particle ideas through various forms of representation that explain the behaviour. There was also a view that there needed to be an emphasis on evaluating the adequacy of a particular representation to explain a particular behaviour. These views are reflected in the following comment by Lyn.

> Lyn: *So what we would have done before is teach the particle theory and then incidentally relate it to real life. But through teaching the year 8s we realised that the model has to sit within everyday experiences. But you know 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, one of the areas I focus on, is how good is the representation?*

Lyn's comment not only expresses a change in a pedagogical practice it also points to an epistemological change whereby the *model has to sit within everyday experiences* and is not separate to how one thinks about explanations of the properties of substances. In thinking about the implications from the ideas about matter pre-test results the teachers shifted to a greater attention to students' prior views.

The greater conceptual focus resulted in a greater perceived awareness of the students' developing understandings of the key ideas. This is illustrated in the following comment by Sally:

> Sally: *I found it a real valuable experience and its interesting how we pick up all these misconceptions and it has been a challenging experience as well.*

Sally saw direct benefit in gaining knowledge of the research literature in terms of students' alternative conceptions at the planning stage in suggesting:

> Sally: *…and on top of that I find it deeply rewarding that here is a list of things that kids often get wrong, and I have a look at them and actually have a chance to stop the kids from developing really deep misconceptions, and I love that.*

Therese (2010 teaching sequence) responded differently to the Lyn and Sally in relation to her students' pre-test results despite results being very similar to the 2008 pre-tests. That is, the students displayed a range of alternative conceptions. This is shown in the following comment where Therese referred to having knowledge of the students' conceptions literature.

> Researcher: *Was there anything surprising for you in these results or were they what you might expected?*
> Therese: *To be honest, I think the pre-test results for any Year 7 class should be quite similar. Therefore, there was nothing surprising for me for my classes.*
> Researcher: *Why is that?*
> Therese: *For my [science teaching] degree most of my assignments dealt with alternative conceptions with any topic. For example, with light, that cats can see without any light but human can't.* [Therese later indicated that she is currently teaching her students about light].

Therese also had a more sophisticated epistemology than Lyn and Sally had initially in respect of the function played by the particle model. When asked, "*what do you see as the main purposes of introducing the particle model to Year 7?*, Therese responded:

> Therese: *I see that the main purpose of introducing the particle model at Year 7 is that it gives the students the foundation of the true essence of Science. We aren't able to see everything in the world around us so we do experiments after experiments to try and make sense of it. The Particle Model enables the students to come up with their own idea of what substances are made up of and how they explain the behaviour of different states.*

This view was reflected in the Year 7 teaching sequence where the initial lessons involved the students exploring properties of different substances, for example, comparing the properties of a rubber band with those of a stick of chalk. Particle ideas were then introduced on the basis to explain a specific property of a substance. For example, after the students had been informed that scientists, whilst being unable to see inside matter, imagine it to be composed of particles the students were set the representational challenge to the state of the particles to explain the property of a piece of paper's ability to hold its shape (see Fig. 1). After students undertook this task three students were chosen to share their representation with the rest of the class. Each representation was evaluated by the class as to whether it served its purpose. Figure 2 provides another example of student generated representations in response to a representational challenge to use particle ideas to explain properties of matter that was given by the teacher. Figure 2 shows three different ways in which the students imagined two different substances. There were different types of particles (Fig 2a), different types of bonds (Fig 2b) and different arrangements of particles and bonding (Fig. 2c).

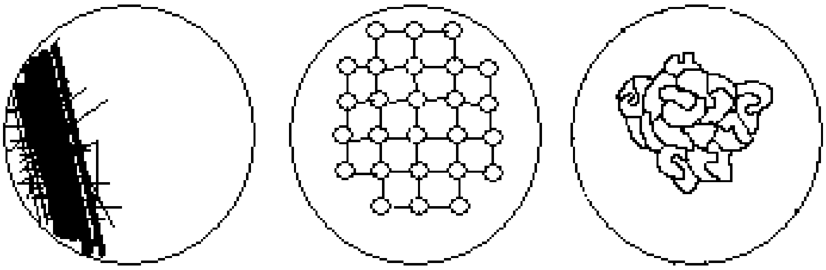
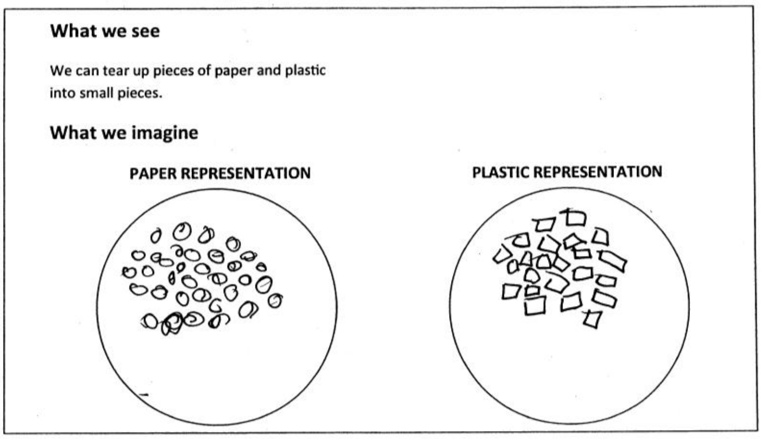
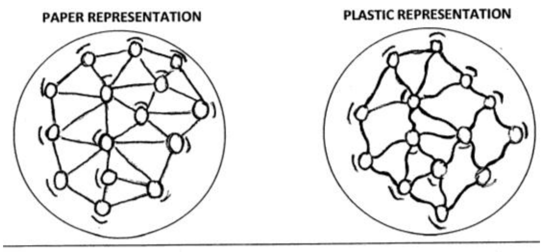


Figure 1 Year 7 students' particle representations to explain how a piece of paper holds its shape



a



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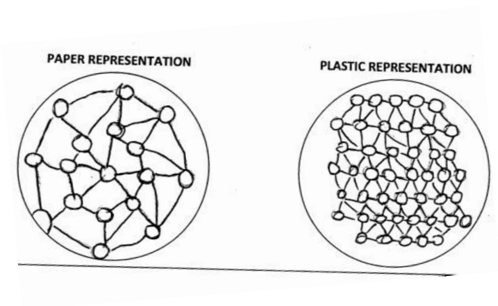


c

Figure 2 Year 7 students' particle representations of different substances

Generation and negotiation of student representations played a significant role in the Year 7 and Year 8 teaching sequences. This opened up more negotiated activities and discussions with students. A greater level of discussion than in previously taught topics is reflected in the following comments.

> **Therese:** *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*
>
> **Sally:** *It's the most rewarding thing taking stuff in their everyday experiences into the science room…that type of conversation would not have occurred before, and that's the richness where you get the kids having science debates and*

> *conversations, rather than delivery of fact; it's a higher order level of thinking and that was really fantastic.*

The teachers had constant movement between macroscopic behaviour of substances and particle ideas through various forms of representation that explain the behaviour. Different particle representations, either generated by the teacher or the students, were discussed in terms of their adequacy in explaining properties of matter. Apart from the iconic pictorial representations of particles as spheres (Fig. 3) other forms, such as a picture of students on a bus, pop corn being made or a section of a jigsaw puzzle were discussed in terms of their particular features to explain macroscopic behaviour of matter in addition to those features that did not explain the behaviour.

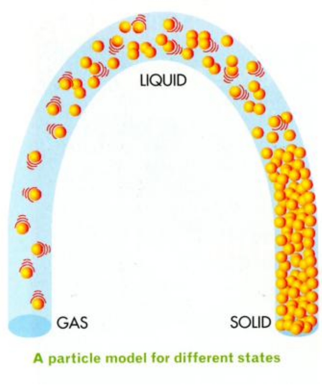


Figure 3. Particle representation of states of matter (Lofts & Evergreen, 2006, p. 86)

Apart from students critiquing each the student generated representation they also critiqued the canonical forms. For example, the Year 8 students critiqued the representation shown in Figure 9 which came from their Year 7 textbook. The students picked up two limiting features of this representation which were the separation of the particle in the liquid state and lack of movement energy shown by the particles in the solid state. In other activities the students were challenged to generate their own representations, whether by role play or in diagrammatic form to explain a variety of specific macroscopic behaviour of matter. For example, 'candle wax goes 'gooey' when the candle is lit' or 'an elastic band breaks when overstretched'.

An awareness of the use of more representational forms than previously practiced was expressed by Lyn when she commented:

> Lyn: *I always used representations but particularly stronger for instructions and then I would just use visual representations…and now I use many different forms.*

An example of where multiple modes of representation relates to a classroom discussion about melting. The stimulus for discussion came from a video of lead being heated over a period of time with the simultaneous production of a temperature versus time graph (Figure 4). The students were asked to relate features of the graph with the images of the lead being heated.

The observation of constant temperature with time during the period in which the lead was melting then formed the basis of another discussion about its explanation using particle ideas.

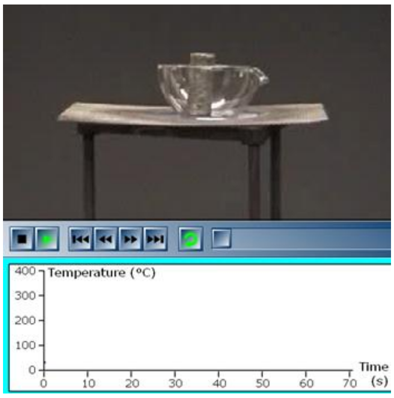


Figure 4 Representations of heating lead[3]

The greater level use of representations was seen by Theresa as coming from the students when she responded to the question '*did you use more representational forms than before?'*

[3] This representational resource is part of a curriculum package of resources produced by Phillip Johnson, University of Durham.

> **Therese:** *Yes, we normally just gave them the textbook representations. Now there is more getting them thinking them up themselves.*

This suggests that Therese had not in previous years undertaken a key feature of the representational pedagogical principles that suggest that student generation and negotiation of representations is important. Lyn felt that in past years her use of representations was narrow when compared to her 2008 teaching sequence. She commented:

> **Lyn:** *I always used representations but particularly stronger for instructions and then I would just use visual representations…and now I use many different forms.*

The three teachers pointed to an enhanced student engagement with a focus on representations as it facilitated student learning.

> **Lyn:** *What's interesting with this approach, Adam, who is very, very difficult, and has a lot of issues, and has been very disengaged and has been very confrontational, he can't help himself to get sucked into the conversations. It's so powerful.*

Sally added:

> **Sally:** *That's the other thing; we don't manage a lot of behaviour, because the lessons are solid lessons.*
>
> **Therese:** *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.*

The three teachers saw representations as tools for learning when they commented:

> **Sally:** *It's good to give them a representation, but it's more powerful when they re-represent it…it helps in their reasoning.*
>
> **Lyn:** *... it's a very powerful way of showing understanding and getting the kids to think. And the other thing too, is it allows kids to be creative in showing their understanding with different representations. And we can all see different ways of doing it.*
>
> **Researcher:** *Do you think its important for students to come up with their own representation?*
>
> **Teacher:** *They get engaged more, its like a puzzle because they have to come up with a specific explanation like how can you explain why a piece of paper holds its shape.*

In terms of content coverage it the unanimous agreement of the teachers that undertaking a representational focus implied by the pedagogical principles means that less content is covered. This is not surprising given that they spent class-time in getting students to generate and negotiate their own and canonical representations, which is something they did not undertake in the past.

> **Researcher:** *In comparing what was done in the past with what you did this year. What do you see were the main differences?*
>
> **Teacher:** *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.*
>
> *We concentrated on some key ideas. If I ask some of my Year 8's now they wouldn't know but my Year 7's would.*

Therese's comment of a *couple of topics blended together* was illustrated with the following exchange where she referred to the early teaching of temperature, the inclusion of bonding and reasons for such phenomena as evaporation and heat transfer.

> **Researcher:** *You taught about temperature very early on. Why was that?*
>
> **Teachers:** *Temperature related to states of matter and is critical to the particle model as energy of particles related to temperature. In the past we never really did bonding but we had the students thinking about bonding in this topic.*
>
> **Researcher:** *Why is that?*
>
> **Teacher**: *Because the students needed bonding to explain the properties of matter that were given as challenges, it explains how a rubber band can stretch.*
>
> **Researcher:** *Were there some things you didn't get to teach?*
>
> **Teacher:** *Yeah, reasons for evaporation and heat transfer. We started to do it at the end but ran out of time.*

In terms of assessment the teachers saw benefit in the knowledge gained from the pre-tests in terms of targeting the teaching in resolving misconceptions that arose and for the students to be made aware of their own thinking as an important part of the teaching sequence.

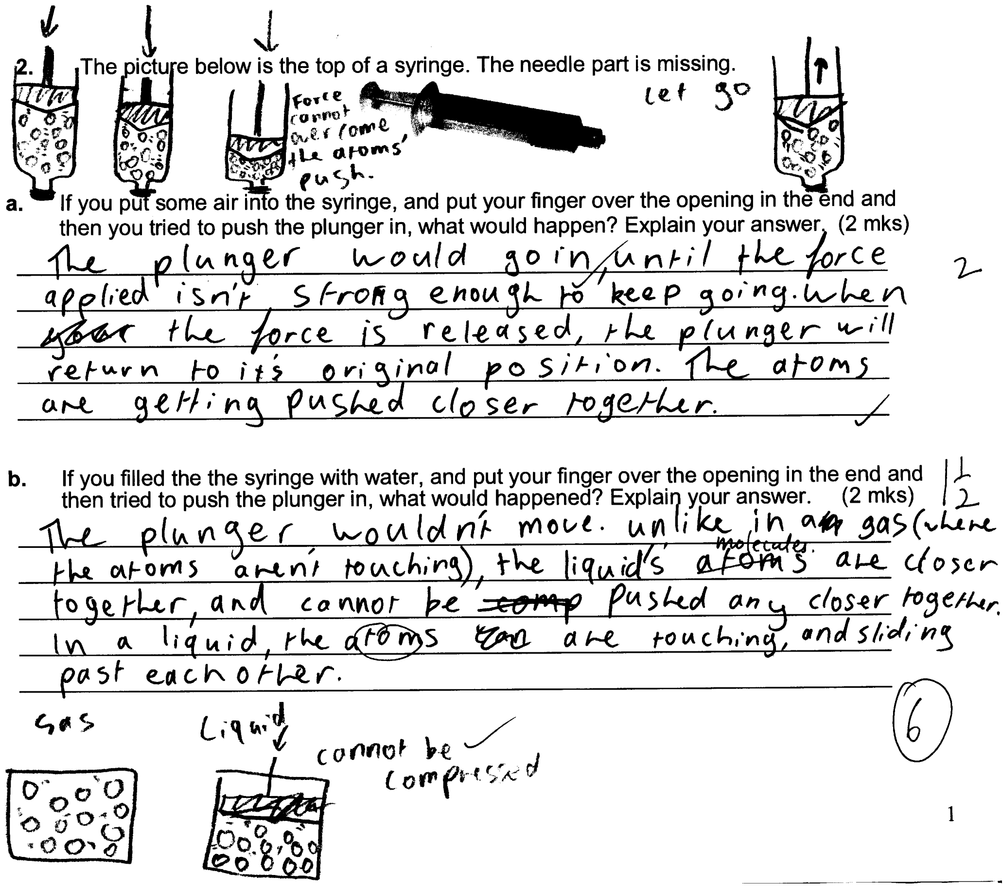
> **Lyn:** *Because we have more understanding of the misconceptions we can teach accordingly and we can single out misconceptions…we can tackle them straight away.. if you are aware of what the misconceptions could be, you are explicitly telling the students that you know some people think this is so, it has a huge impact because the kids will not then go along those lines…The pre-test was used as a basis to begin discussions, it gave kids a good reference point.*
>
> **Sally:** *…for an example I said all 50% of you thought this of the answer, it was such a powerful thing because we got them saying, "Oh there are other people in the class who thought that was the answer."*

There were many instances during the teaching sequences whereby the students were given the opportunity to interpret and generate representations which gave the teachers a good sense of student learning from a formative and summative perspective.

> **Lyn:** *…what you're seeing with representation is that you're seeing what's in their brain, not what they're regurgitating.*
>
> **Researcher:** *You often had students evaluating each other's representations.*
>
> **Therese:** *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.*

Figure 5 below shows a response by a 2008 Year student to a post-test question. In an interview with the student the following exchange revealed that a text response was the preferred representational mode.

> **Researcher:** *What's you reason for having a diagram here?*
>
> **Student:** *Just to explain it a bit better. It's kind of hard to explain things like this when you can't picture it so I thought I would draw a diagram just to help that.*
>
> **Researcher:** *Because there are so many lines there did you think you were obliged to fill them with words?*
>
> **Student:** *I don't think I had to use words, I could have just drawn a picture, but the teacher did say that if you have that many lines then you need to fill them*


2. The picture below is the top of a syringe. The needle part is missing.

Force cannot over come the atoms' push.

let go

a. If you put some air into the syringe, and put your finger over the opening in the end and then you tried to push the plunger in, what would happen? Explain your answer. (2 mks)

The plunger would go in, until the force applied isn't strong enough to keep going. When the force is released, the plunger will return to it's original position. The atoms are getting pushed closer together.

2

b. If you filled the the syringe with water, and put your finger over the opening in the end and then tried to push the plunger in, what would happened? Explain your answer. (2 mks)

1
2

The plunger wouldn't move. unlike in a gas (where the atoms aren't touching), the liquid's molecules are closer together, and cannot be pushed any closer together. In a liquid, the atoms are touching, and sliding past each other.

Gas

Liquid

cannot be compressed

6

1

Figure 5 Year 8 student response to a pot-test question

The 2008 teachers felt that future tests should provide generous spaces without any line for students to respond. This would allow students to provide a variety of representational forms. This was what occurred for the paper-based tests administered to the Year 7 students in 2010. In addition, the students had large poster workbooks to use as workbooks. When Therese was asked:

Researcher: *Did you see any benefit from students using the large project books?*

Therese: *Yes, the large project books were a benefit. It gave opportunity for the students to answer their question in picture form if they wanted to because with particle ideas more often than not, it was easier for them to draw their answer.*

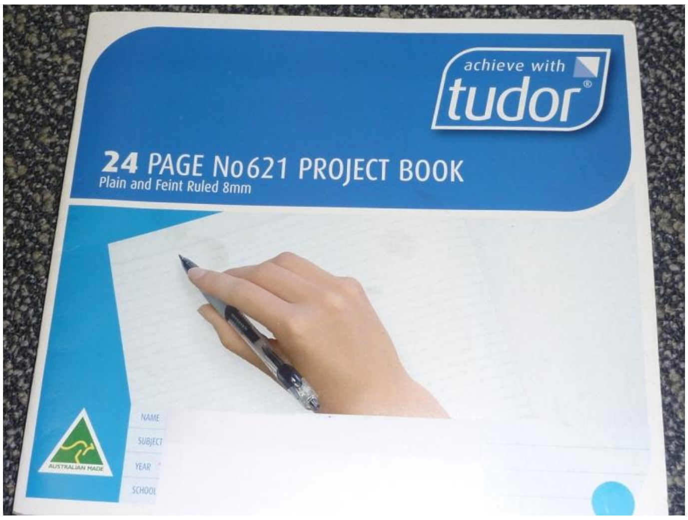


Figure 6 Project books used by the 2010 Year 7 students

Discussion and conclusion

A key implication of the study is the need to shift practice in teaching science from its current focus on the delivery of content that is conceived of as resolved knowledge structures, to the pedagogical practices of this representation approach based on a discursive, more active view of knowledge and learning. This will require changes in conceptions of the role of the teacher in the science classroom, and changes in how knowledge and learning are thought of in science. To make this change, teachers need to:

- understand the role of representation in learning science, implying both a pedagogical and an epistemological shift;
- provide a representation rich environment and opportunities for students to negotiate, integrate, refine and translate across representations;
- make explicit to students the role of representation in learning science; and
- conceptualize learning in science in terms of students' induction into the representational conventions and practices of science and their capacity to coordinate these.

Given current concerns about the engagement of students in meaningful science learning, and the relatively limited success of pedagogical approaches based on cognitive views of learning, we would argue that this is an agenda that needs to be vigorously pursued both in research and policy.

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