The impact on teaching practice through adopting a representational focus to teaching science

Peter Hubber,

Filocha Haslam,

Russell Tytler,

Deakin University, Australia

Email Contacts:

Peter Hubber phubber@deakin.edu.au

Filocha Haslam maria.f.haslam@deakin.edu.au

Russell Tytler tytler@deakin.edu.au

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Abstract

A large body of research in the conceptual change tradition has shown the difficulty of learning fundamental science concepts, yet conceptual change schemes have failed to convincingly demonstrate improvements in supporting significant student learning. 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. The researchers worked with two experienced teachers in planning two teaching sequences in the topics of 'force' and 'substances' using a teaching approach that highlight representational issues and options in helping students explore and develop key conceptual understandings. Classroom sequences involving the two teachers were videotaped using a combined focus on the teacher and groups of students. Video analysis software was used to capture the variety of representations used, and sequences of representational negotiation. The teachers reported substantial shifts in their classroom practices, and in the quality of classroom discussions, arising from adopting a representational focus. From an epistemological perspective the teachers came to terms with the culturally produced nature of representations of force and substance and their flexibility and power as tools for analysis and communication, as opposed to their previous assumption that this was given knowledge to be learnt as an end point. From this perspective they learnt to use representational challenges to drive classroom discussions, and as they themselves achieved greater understandings of their use in interpreting force and motion situations and applying particle ideas to explain properties of substances. From a pedagogical perspective the representational approach was acknowledged to place much greater agency in the hands of students, and this brought a need to learn to run longer and more structured discussions around conceptual problems.

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). 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. These principles draw on literature that emphasise the active role of representational work in supporting learning in science (Greeno & Hall, 1997; Ford & Forman, 2006) and formed the

[1] This study is part of a wider research project titled, *The role of representation in learning science*, conducted at three university sites.

basis of advice to the teachers concerning the nature of an effective representational approach. The principles suggested that:

1. multiple representations of force and substance should be introduced and encouraged,
2. students should be encouraged and supported to generate their own representations,
3. representations of force and substance should be introduced and used as tools for thinking and communicating rather than as fixed entities to be learnt,
4. there should be explicit discussion and evaluation of the adequacy of representations in generating meaningful understandings,
5. there should be continual links with perceptual activity built around activities and objects, and
6. sufficient time should be allowed to adequately explore the meaning of representations.

There is considerable evidence that teacher characteristics strongly influence student learning outcomes (Barber & Mourshed, 2007; Darling-Hammond, 2007), and that any pedagogical reform program needs to support teachers to adjust their beliefs and practices in line with the innovation, if it is to succeed. In addressing the difficulties students have in learning fundamental science concepts Danaia and McKinnon (2008) suggest that teachers need to have some understanding of common alternative conceptions, including ways of dealing with those alternative conceptions their students bring to the classroom. Bakas and Mikropoulas (2003) point out that the sometimes limited success of conventional teaching methods in overcoming students' alternative conceptions may be due to a lack of appropriate teaching aids in the form of representations that can intervene dynamically in the learning process and modify it.

A teacher's professional knowledge includes content knowledge of the discipline of science and pedagogical content knowledge (PCK, Shulman, 1986). Shulman (1986) defined PCK as "the way of representing and formulating the subject that make it comprehensible to others... an understanding of what makes the learning of specific topics easy or difficult (p.9)". Gell-Newsome (2001) makes the point that superficial content knowledge may restrict the ability of the teacher to teach in a creative and innovative manner, which encourages and makes use of students' questions. Instead, teachers with a superficial content knowledge tend to limit the use of students questions in classroom discourse and the development of conceptual connections. To support teachers who lack content knowledge Cohen and Hill (2000) suggest that professional development should focus not only on content but also pedagogy. This view is supported by Brunsell and Marcks (2005) who state that professional development in science education should, "focus on providing teachers with a coherent structure and methods of communicating that structure to students…. [and] continuing support to participants as they deepen their content understanding and change their teaching practices (p. 46)".

In this project we worked closely and collaboratively with teachers to construct teaching sequences in key conceptual areas. In this work we developed and validated the pedagogical principles. In each of these sequences the content was outside the teachers' discipline expertise so the challenge for them was a combination of content knowledge and pedagogic content knowledge. This paper explores how teachers responded to the new approach, implied by the principles above, and the changes in their practices and beliefs that accompanied this.

Research Methods and Question

The researchers worked closely with two experienced teachers, Lyn and Sally[2], to plan two teaching sequences that highlight representational issues in helping students explore and

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

develop key conceptual understandings. The sequences in the topics of forces and substances sought to develop a model of classroom practice that foregrounds representational negotiation as a basis for conceptual growth. A Forces topic was taught to Year 7 students (12 year-old) and the second topic on substances was taught to the same students six months later when the students were now in Year 8. About 12 lessons, lasting 45 or 90 minutes, were allocated to the teaching of each topic.

Research Question

The research question was: What impact was there on the participating teacher's practice and beliefs through the adoption of a representational approach to teaching science?

Data Collection

Data collected included: (1) video recordings of most classroom sessions and of student interviews; (2) student workbooks; (4) pre- and post-tests (for substances topic only); (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. Data reported in this paper include interpretive perspectives and examples from various contexts and settings.

Approach to planning the topic sequences

In coming into this study Lyn and Sally were experienced practitioners who were capable of innovative use of strategies based on the development of students' representations. Both teachers were biology trained and specialised in teaching this subject at senior levels of schooling but taught general science at junior levels. From this perspective the topics of forces and substances were outside their main area of expertise.

The initial approach to planning the topic sequence was similar for each topic. In planning the sequence with the teachers the adoption of a representational focus puts stringent demands on clarifying what knowledge was to be pursued. The teaching sequence therefore needed to be informed by a clear conceptual focus. At the planning stage, in order to refine the representational work, the research team collaborated with the teachers in identifying big ideas or key concepts of the topic in addition to the students' alternative conceptions reported in the literature. The initial lessons in each teaching sequence focused on exploration of students' prior views, generation of students' representations, and introduction of the scientific conventions that underpinned each topic. Each teacher followed a similar sequence of activities, but in fact each was different in the way they introduced ideas, led discussions, and achieved some form of closure. To provide some insight into the specific approaches undertaken by the two teachers the following case is given:

Case of Lyn – teaching forces

What is described here is an outline of the first few lessons of the forces teaching sequence as taught by Lyn. The lessons are described as a series of sequenced stages.

Sequence stage 1

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*. 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. This was 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, pulls or lifting forces, to mime the size of forces, and to indicate the force's direction and points of application.

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.

Sequence stage 2

Lyn 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 shared, discussed and evaluated within a whole class discussion.

Student 1 Student 2

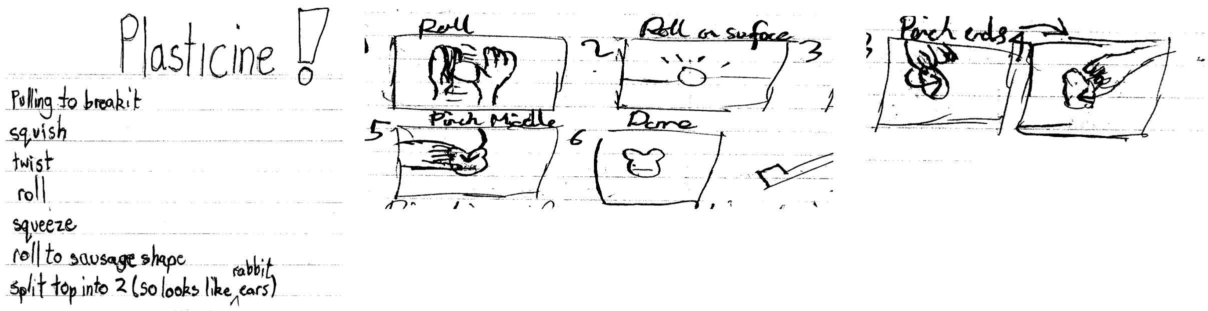

Fig. 1 Student representations of manipulating plasticine

One representation which had a series of figures with sequenced annotation (Figure 2 Image A) was unanimously accepted as providing clarity of explanation of the actions that were undertaken. This is illustrated by the following commentary extracted from a video segment:

> Lyn: *Which one of these representations worked well in explaining what was done?*
>
> Student 1: *John's (image A) because it should you exactly what to do. Mine could have ended up anything.*
>
> Student 2: *It (image A) 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.*

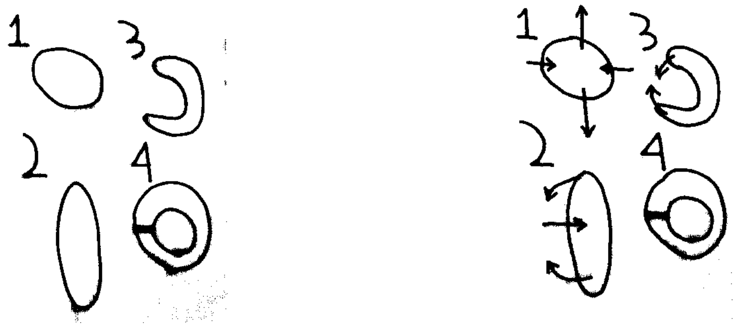

Image A Image B

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

Sequence stage 3

Lyn introduced force diagrams, which use the scientific convention of representing forces as arrows. She did this by discussing with the students the benefits in drawing 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).

Student 1 Student 2 Student 3

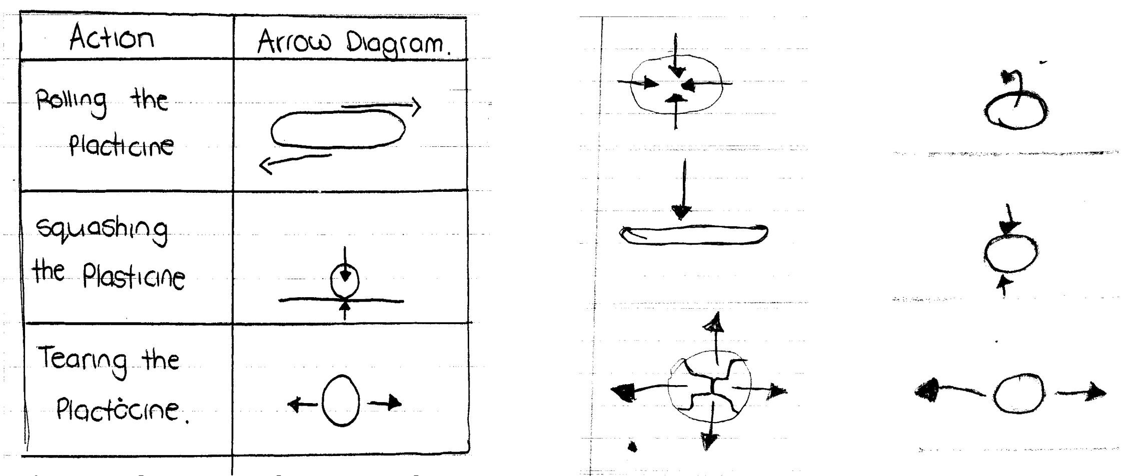

Fig. 3 Students' use of arrows in their representations

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, and which included:

- 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.

Sequence stage 4

Lyn introduced the scientific convention of representing forces as straight arrows, when the base of the arrow is the application point of the force, the length of the arrow gives an indication of the strength of the force, and the arrow head indicates the direction of the force. The students were then encouraged to apply this convention to various everyday situations where forces are applied. Two examples of these include: (i) students were each given an empty soft-drink capped bottle and asked to represent the forces needed to twist off the bottle cap (Figure 4 Image A), (ii) students were given a piece of plasticine and asked to stretch the it with a gentle stretch and a rough stretch. They were then asked to use the arrow convention to represent a gentle, and a rough stretch on the plasticine (Figure 4 Image B).

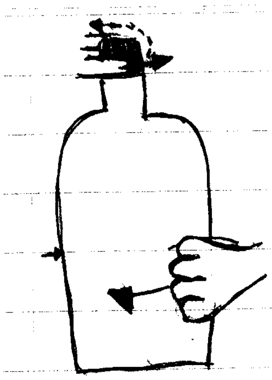

Image A

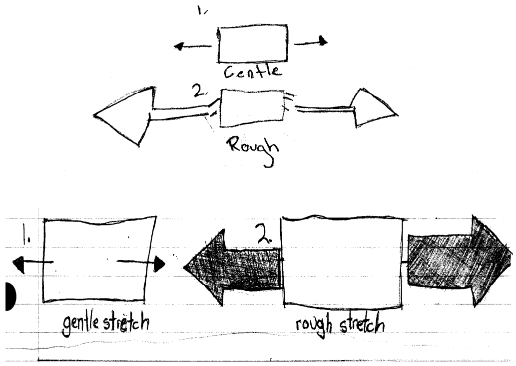

Image B

Fig. 4 Student exploration of the arrow representation of force

Findings

The sequences resulted in a number of insights into the efficacy of a representational focus in planning and implementing a lesson sequence in science. The analysis will particularly focus on the experience of the teachers in coming to understand this representational focus and its impact on pedagogy, and on their views about what it is to learn, and to know in science.

The findings described in this section are categorised as:

- Teacher pedagogy;
- Teacher epistemology;
- Richness of the representations generated; and
- Teachers' views on student learning and engagement.

Teacher pedagogy

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, the following points give one of a number of key ideas from each topic:

- Forces are pushes or pulls of one object onto another; forces may be represented in diagrams with arrows.
- The particles that make up the substances do not share the properties of the substance they make up.

The planning stage also incorporated, within a workshop format, discussions of the alternative conceptions literature which was used with the key ideas in developing, and exploring, teaching and learning activities with a representational focus.

In taking a conceptual focus to topic planning the teachers moved away from their previous practices. In respect of the forces topic the teachers in previous years taught a three-week teaching sequence. The focus was in covering the curriculum content contained in the students' textbook (Lofts & Evergreen, 2006), and the title of the topic, "Forces in Action", matched the chapter title in the textbook. The chapter moved quickly through a range of forces, for example buoyancy and surface tension, electrostatic forces, magnetic forces, electromagnetic forces and, gravity and air resistance. During the planning stage the teachers gained confidence and a realisation of the need to move away from the textbook that framed their pedagogical approach. Lyn commented:

> Lyn: *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.*

The contexts with which to explore the key ideas were far less in number than what was contained in the textbook. They included forces in everyday situations, gravity, friction, and floating and sinking. Therefore, the curriculum coverage for the forces topic taught with a representational focus was far less than in previous years with its textbook focus, thus illustrating the 'less coverage more depth' principle of current science education reforms.

For the substances topic the 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 pre-test results the teachers shifted to a greater attention to students' prior views. 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. …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.*

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."*

The two teachers were strongly of the opinion that this representational focus had significantly impacted on their classroom practice. In the teaching sequences, it became clear from the video record that both teachers were:

- Opening up more negotiated activities and discussions with students;
- Paying more attention to language and to representational conventions generally; and
- Encouraging more modes in explanations.

These points are illustrated in the account of Lyn's forces teaching sequence above. In the forces topic there was explicit discussion of representations such as those associated with explaining the action of forces in everyday events. The development of the scientific convention of straight arrows representing forces was embedded in an authentic need to know and opportunity involved discussions on the partial nature of this convention in explaining forces. The students found that other visual representational modes such as drawings with annotations and curved arrows to indicate motion can enhance the explanation of an everyday action like screwing the top off a bottle of drink.

As has already been stated, in the substances topic the teachers had changed their previous practice of teaching the particle model as a body of knowledge in itself to have constant movement between macroscopic behaviour of substance 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. 9) 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.

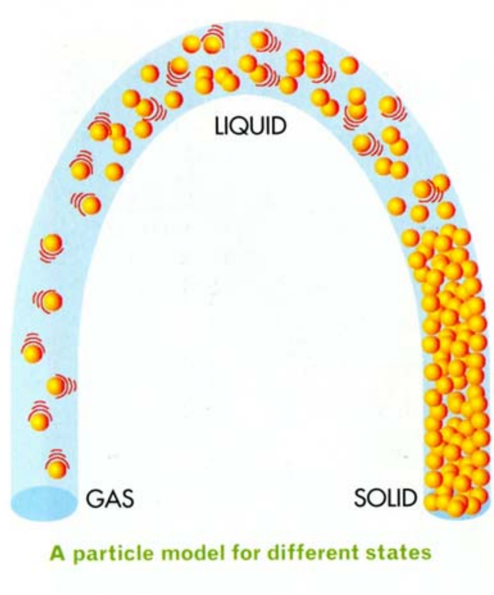

Fig 9. Particle representation of states of matter (Lofts & Evergreen, 2006, p. 86)

Figure 9 is taken from the Year 7 text the students used the previous year. The teachers made this representation a focus of discussion about its adequacy with the students; this was something that was not done in the previous year. The students picked up two limiting features of the representation which were the large separation of the particles 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'.

The two teachers reported there was a significant pedagogical change in the manner in which the topics were introduced in the classroom compared to their previous practice. They reported on the need to negotiate with the students the scientific conventions such as the use of arrows for forces or particle model of matter. This negotiation takes some time but provides a springboard for a deeper understanding.

The teachers also reported that the language used by teachers, and students, was more open and exploratory. There was a greater emphasis in developing the scientific terminology through drawing on the students' everyday experiences and language [L1] (Yore, 2008; Yore & Treagust, 2006), such as in the plasticine manipulation sequence described above where teachers supported students to re-categorise their own words into 'push' or 'pull' before introducing the scientific language (L3) (Yore, 2008; Yore & Treagust, 2006) of force defined as 'a push or a pull of one object onto another'. The teachers realized they need to transform their language of instruction [L2] (Yore, 2008; Yore & Treagust, 2006) to reflect the translations they were expecting of the students.

There were many instances where everyday experiences were either introduced by the teacher or were brought into class discussions by the students. The teachers found this to be a positive outcome of the teaching sequence. They also considered that the amount of discussion was more than experienced in previously taught science topics. These perspectives are illustrated in the following comments by Lyn and Sally.

> Lyn: *It's the most rewarding thing taking stuff in their everyday experiences into the science room and that's fantastic… kids were saying what would happen if it happened on the Moon and a couple of situations like that…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.*

> Sally: *there were more discussions, it wasn't a little bit of theory and let's do a prac, or let's just go straight into a prac, talk about what we just did it was a lot more application how does it work in the real world kids were given time to actually think.*

The teachers also reported on a change to their practice in terms of the need for a greater level of explicit discussions about mathematical ideas, such as those relating to graphs, in the science classroom. This was evident when the teachers were asked to comment on the researcher's observation of classroom discussions about different aspects of graphs just after the teaching of the forces topic.

> Amy[3]: *We never really teach them [graphs] in science. But now we are saying [to the students] well what kind of graphs do we do? Why should it be a line graph or a bar graph? Well, now we talk about continuous data… I just thought that this is a mine field that we never explicitly taught that. Graphs need to be explicitly taught as it comes to that bit. So, doing graphs, was really, really rich.*

Teacher epistemology

In the planning discussions with teachers for the first topic of forces it was clear that as a group they had a limited view of representational issues in teaching and learning science. They tended to take the representational conventions traditionally associated with this topic as given, to be learnt as part of coming to a resolved understanding of force. For example, when asked what changes occurred in their teaching of forces by taking a representational focus Amy said:

> Amy: *The main difference for me is the not too subtle one - when we taught forces previously you just barrel in, you start using arrows straight away, they just become*

[3] Amy was a participating teaching in the first topic on forces but not in the other topics on substances.

> *incidental, so we never took the time to introduce the arrow or the significance of it… as representing force at all previously.*

The teachers were surprised that such apparently resolved representations, such as arrows to represent forces, could be the subject of classroom discussion. They now believed that understanding involves learning to generate and use representations to analyse and communicate a science idea, rather than learning a concept or a representation as an end in itself. This belief carried through into the other topics taught. Six months after the materials topic the teachers expressed an epistemological view that understanding and learning is a processes of representing and re-representing ideas in different modes as evidenced by the following comments by Lyn.

> Lyn: *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.*
>
> Researcher: *So is it two-way?*
>
> Lyn: *A circle. The representations helped our knowledge and our knowledge helped our representations and the more representations helped our knowledge and the more knowledge helped our representations. So it was more a continuous feedback working.*

In taking a representational approach Lyn suggested,

> Lyn: *Yes, I think it gave the kids a really good structure to explain things. It was good to take the time to really explain things, sometimes we do it and the kids are not part of it.*

However, the demands of undertaking a representational approach can be challenging as illustrated by Sally's comment that:

> Sally: *You come into class with some certain concepts that you want to deliver and you end up with a lesson that is totally different to what you planned because it is usually directed by the students. The questions they ask are challenging they ask questions I can't answer to a level or a point that the kids can understand [as] they don't have that background knowledge so we try and simplify for them and it is not easy.*

Thus, this approach to teaching and learning has significant epistemological implications for teachers, leading to a position where knowledge is seen, not as a resolved set of declarative concepts, but as a network of interlocking representations that are to some extent negotiable and 'in process'. For the teachers this meant a change in their topic planning practices where they believe that planning for topics now involves preparing for possible changes in direction which result from current classroom interactions rather than following a fixed planning schedule. The following comments made by Sally reflect this thinking.

> Sally: *…you plan your lesson with a lot of possibilities. You think about okay what if the students ask me this question, what kind of activities can I have and I'm a little bit more prepared so my lessons are not …now way back, if I did this last year, I would've prepared a whole 5-week lesson and I'd be teaching it lesson, by lesson, by lesson. So that's the progression.*

Richness of the representations generated

It was clear in the lessons, observing both teachers and students, how naturally they resorted to different representational modes. The different categories of gestural, textural, visual and mathematical representations all were evident during the teaching sequences. 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.*

Representations of force, for instance, included hand gestures by the teacher and students to accompany their verbal explanations, using scientific and everyday language, of everyday instances that involved the use of forces. In discussions about the forces involved in opening the screw cap of a soft drink bottle students were given an actual bottle to manipulate. The students were expected to translate their physical actions of opening the bottle into a visual representation that initially employed their own drawings and, later, to represent the actions in symbolic form using the scientific convention of straight arrows to represent forces. In doing this the students came to appreciate the partial nature and adequacy of representations. For example, the use of straight arrows representing forces.

An example of where multiple modes of representation were used in the substances topic related 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 10). 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.

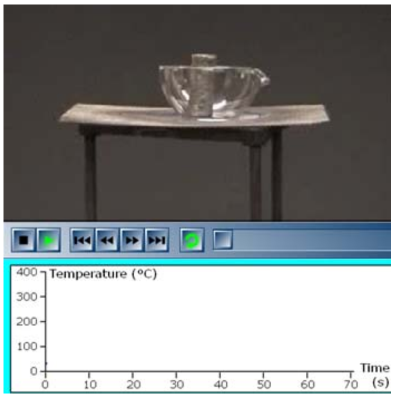

Fig. 10 Representations of heating lead[4]

It was clear from the video record that over the period of the two topic sequences the teachers gained in confidence in setting representational challenges that led to significant student representational activity. As the sequences progressed they relied less on the support from the research team through the generation of their own resources or changing activities that were discussed in the initial planning stage.

In terms of enhancing students' learning with a representational focus both teachers made reference to the positive effects of providing the students with representational challenges and emphasising the partial nature of representations. These points are reflected in the following comments made by Sally and Lyn.

> Sally: *It's good to give them a representation, but it's more powerful when they re-represent it.*
> Lyn: *I really love the emphasis on what does it [representation] show, what it doesn't show. That was never a part of my vocabulary before which was really sad, or at least not formally anyway… and for the students when they give you the representation, you say 'okay well lets put it up there and see what the other kids think' … it adds a lot more involvement and ownership by the kids, I think it is fantastic.*

Throughout the topic sequence the students were regularly challenged and supported to coordinate representations as a means to express coherent, defensible and flexible understandings. To support the students the teachers saw the need for them to provide the students with the skills in identifying the roles played by representations in explaining science and as tools for learning. Lyn commented:

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

> Lyn: *…we found that we had to teach the students the skills, and understanding how the representations work and what they mean…by you explaining about representation all the time, you're creating a context where the kids can learn; they've got some tools to do some real thinking with. And representations give them some kind of tools for what you gotta focus on…It's a skill that kids have to develop over a period of time. You can't just give it to them at once. It's like drawing graphs. The kids have increasing discrimination of how to draw graphs over many many years because they are told explicitly you have to do this stuff. [Similarly] we have to do this with representations because it does not come naturally.*

There were many instances during the teaching sequence 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.

> 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: *...what you're seeing with representation is that you're seeing what's in their brain, not what they're regurgitating.*

Views of student learning and engagement

The two teachers were strongly of the opinion that this representational focus had significantly impacted on student learning and engagement. Their perceptions of improved learning and engagement were central to their acceptance of change outlined in the previous sections of the findings.

Students, in discussing their learning, used richer language than might be expected with a focus on resolved concepts. For example, the following two written responses by students show how they used analogies to explain gravity.

> *Gravity is an invisible brick holding things down.*

> *Gravity is a force pushing down on the Earth, kind of like a magnet attracting everything to the surface of Earth*

When asked if the introduction of the different representations paid off in terms of student learning Lyn responded:

> Lyn: *Yes, I think it gave the kids a really good structure to explain things like. It was good to take the time to really explain things, sometimes we do it and the kids are not part of it…it sets up the rest of the unit and it gives them a really good structure to the concept that they can start to think in terms of something that is quite concrete for them, whereas before we were flinging the terms around more and it was more a pot pori and they didn't come out thinking any more about forces than when they came in with*

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.

> Researcher: *So do you think now because the students get the opportunity to represent in different ways that that's enhancing their learning?*

> Lyn: *Absolutely. One of the kids that's quite slow at picking things up, 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: *So 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. 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.*

The teachers found that improved student engagement was generated by the teaching approach addressing their questions. This view is illustrated by the following comment by Sally and Lyn.

> Sally: *I found most of the lessons were more student-driven…it was built up because of their questions. I think the kids appreciate the fact that they could openly discuss why they thought that was the answer and that discussion was really powerful …they valued the fact that they wanted me to know what they were thinking.*

Both teachers pointed to an enhanced student engagement through the adoption of a representational approach.

> 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.*

Discussion and conclusions

In this study the teachers confirmed the efficacy of a representational focus in teaching and learning the key science concepts in the topics of force and substances. The teachers felt that the approach they adopted reflected the pedagogical principles listed in the introduction.

The teachers reported substantial shifts in their classroom practices and beliefs in response to an explicit representational focus in teaching science. From a pedagogical perspective this approach was acknowledged to place much greater agency in the hands of students, and this brought a need to learn to run longer and more structured discussions around conceptual problems. Both teachers were very positive about this change in their teaching, and the video record showed increased confidence in guiding discussion over the two topics that were taught.

The teachers took more of a conceptual focus to topic planning moving away from a practice of covering curriculum content contained in the students' textbooks. In doing so the teachers sacrificed content coverage for the greater depth offered by this approach, and were unanimous that this change paid dividends in student learning. The representational focus meant that the content to be covered was conceived of as an interconnected set of ideas linked by representations. This interconnectedness and a greater involvement of students in classroom interactions leads to a greater flexibility is required in terms of what content is to be covered each lesson. For the teachers this meant a change in their topic planning practices where they believe that planning for topics now involves preparing for possible changes in direction which result from current classroom interactions rather than following a fixed planning schedule which was their previous practice.

The teachers reported on a greater attention to students' prior views than previously practiced. The saw the knowledge gained from diagnostic test results as beneficial in terms of targeting the teaching in resolving misconceptions and for the students to be made aware of their own thinking as an important part of the teaching sequence. The teachers saw that the resolution to resolving the students' naïve conceptions as very much a representational issue in terms of the use of representational challenges to drive classroom discussions. The students were given many opportunities to interpret and generate representations which gave the teachers a good sense of the students' learning from a formative and summative perspective.

From an epistemological perspective the teachers came to terms with the culturally produced nature of representations in the topics of force and substance, and their flexibility and power as tools for analysis and communication, as opposed to their previous assumption that this was given knowledge to be learnt as an end point. These realisations became empowering as they learnt to use representational challenges to drive classroom discussions and to achieve greater understandings themselves to interpret force and motion situations and apply particle ideas to explain properties of substances. This meant that over the two topics the teachers enhanced their content knowledge and pedagogical content knowledge which was driven by undertaking the representational focus.

The teachers reported on the use of more modes of representation and over the period of the two topic sequence the teachers gained in confidence in setting representational challenges that led to significant representational activity. As the sequences progressed they relied less on the support offered by the research team through the generation of their own representational resources. Throughout the topic sequence the students were regularly challenged and supported to coordinate representations as a means to express coherent, defensible and flexible understandings. To support the students the teachers saw the need for them to provide the students with the skills in identifying the roles played by representations in explaining science and as tools for learning.

The two teachers were strongly of the opinion that this representational focus had significantly impacted on student learning and engagement. Their perceptions of improved learning and engagement were central to their acceptance of change to their practices and beliefs.

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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