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Promoting accomplished science teaching through pedagogical research

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Russell Tytler, Peter Hubber, Deakin University, Australia

In this paper we will examine Shulman's notion of signature pedagogies for its usefulness extended to school science, to analyse a representation-intensive pedagogy that lays claim to bringing school science closer to the knowledge building practices of science itself. Two case studies of teaching and learning will be presented based on research in primary and secondary schools that involved working closely with teachers to develop and validate the pedagogy. Video images of classrooms, interviews with students and teachers, and documentation of students' work, were used to construct insights into the teaching and learning process. It is argued that Shulman's notion of professional practice as involving apprenticeships of knowledge, practice and identity provides a useful lens through which to view this innovation. Shulman's characterisation of signature pedagogy is used to identify key features of the approach.

Introduction

Shulman's (2005) breakdown of professional education has been influential in writing about professional education. Shulman argues that an effective education for a profession is structured around the need to initiate novices into three apprenticeships, namely in:

- Thinking: an intellectual and cognitive apprenticeship involving knowledge and ways of thinking
- Performing; involving apprenticeship in the norms of expert practice
- Conducting themselves: an apprenticeship of identity involving the making of meaning, and introducing the values of the professional community.

The mark of professional expertise is the ability to both act and think well in uncertain situations. The task of professional education is to facilitate novice's growth into similar capacities to act with competence, moving towards expertise. In order to do this, students need access to forms of social interaction that embody the basic understanding, skill, and meaning that, together, make up professional activity (Sullivan, Colby, Wegner, Boyd, and Schulman 2007, p. 9)

Professional training is thus premised on the notion that professionals need to develop schemas for thinking and acting which enable them to bring their knowledge to bear on new situations in ways not possible for novices. This is in marked contrast to traditional ways of training (and teaching in schools), that deal largely with the building of knowledge, assuming a conceptual deficit model of the learner (Margetson 2000). We can view Shulman's characterisation of professional education as aimed at establishing a much more active, praxis-based view of what it is to learn and to be a member of a profession

From this structural analysis of professional apprenticeship, Shulman describes a set of common pedagogies that are used in the professions to develop these professional knowledges, practices and values:

Pedagogies of uncertainty - A characteristic of all professions is that they are fields in which people make decisions and act under conditions of unavoidable uncertainty. Teaching thus involves socialising future professionals to these conditions of practice, and thus

depends heavily on student responses to one another and teacher adaptations of material, because it is impossible to know how the conversation will develop.

Pedagogies of engagement – Learning is unlikely to occur unless students are responding in ways that show they are engaged with the material. A necessary degree of engagement, which is clearly a prerequisite to all effective learning, is built into professional training pedagogies.

Pedagogies of formation - These are pedagogies that build identity and character, dispositions and values. They aim to teach habits of routine analysis.

School science pedagogy – does the notion of signature pedagogy fit?

Central to this paper is the question of whether a school subject be seen in some sense as part of a pathway to the education of professionals in the discipline. Can, and should school science could be seen as the beginning process of preparation of future scientists? There are at least two ways in which this notion can be misleading and even disruptive. First, the major aim of scientific literacy, currently generally agreed as underpinning contemporary science curriculum movements, explicitly shifts focus away from thinking of school science in terms of the beginnings of the training of science researchers and towards thinking in terms of educating the future citizen. Second, school science is removed in time and context from professional training so it could be argued that school education should be concerned with wider agendas and matched to the learning needs of adolescents rather than of adult professionals.

However, in mounting the argument for the relevance of the signature pedagogy construct to school science, there are a number of distinctions we can make. First, the scientific literacy construct has morphed over recent years to focus not only on the education of future non-scientist citizens, but also on future science professionals (Roberts 2007). In both cases there is an increased concern that citizens and scientists alike need to understand the nature of science (NOS); the way evidence is used in the generation and justification of science ideas (Simon, Erduran & Osborne 2006) and the way science interacts with society. Thus, there has been a shift away from considering the knowledge products of science as the central focus towards greater attention being given to the epistemological foundations of the discipline. Second, there has been increasing recognition that standard accounts of the conceptual products of science pay too little attention to the role of language (Klein 2006; Lemke 2004) and that there is a close association between the notion of scientific literacy and an apprenticeship into the discursive practices, the ‘literacies’ of science (Norris & Phillips 2003). Socio cultural perspectives emphasise the communal nature of knowledge building in science and the need to represent this in the science classroom (Tytler & Prain 2009). Third and finally, there is concern (Tytler 2007) that school science tends to focus on the conceptual, historical tracings of science rather than its contemporary practice, and an argument that all facets of the communal practice of science should be represented in the school curriculum. Given the increasing importance of sociological perspectives on scientific practice (e.g. Latour 1999) that demonstrate a more complex and contextual view of the generation and justification of theory in science, this represents an argument for a more complex and contextual approach to school science curricula (Duschl & Grandy 2008)

Thus, contemporary thinking about the purposes and aims of school science now puts greater emphasis on the way knowledge is generated and established in science, its contemporary interactions with societal contexts, and the discursive practices through which we know and learn science. This focus on the actual practices of science, as distinct to the public face of

science expressed as tried-and-true knowledge, can be linked to the sociologist Erving Goffman's (1959) distinction between 'front' and 'back' regions. Goffman contrasted the restaurant, to which the public is admitted, to the kitchen, which is restricted to professionals and where preparations are made and production occurs, as an example to illustrate the distinction. Roesken and Toerner (2010) pursue this metaphor for mathematics education, asking the question; how much do mathematics teachers know of the back regions of mathematics? and link Goffman's metaphor with Shulman's distinction between the surface structure (front region) of a pedagogy and the deep structure (back region). For Shulman (2005), the surface structure "consists of concrete, operational acts of teaching and learning, of showing and demonstrating, of questioning and answering, of interacting and withholding, of approaching and withdrawing" (p. 54). The deep structure involves "a set of assumptions about how best to impart a certain body of knowledge and know-how" (p. 55). In our terms, Goffman's distinction relates to the actual practice of generating science knowledge compared to the public expressions of knowledge products that is the stuff of science texts (including research papers) and media reports. In arguing to move school science further towards representing the actual practices of contemporary science professionals, we are interested to explore whether Shulman's perspective, which involves a similar shift towards emphasising professional practice rather than simply knowledge, can provide a useful perspective in identifying the nature of classroom practices that fulfil this aim.

Traditional practice in science classrooms has long been associated with a pedagogy that is teacher directed and focused on the establishment of understanding of key ideas in science and their applications – the first of Shulman's apprenticeships. This pedagogy is less concerned with introducing the practices and values of contemporary science than the establishment of well honed conclusions derived from the history of such practices. The pedagogy is deeply authoritarian in structure and promotes an apprenticeship of knowledge and insight rather than practice or values.

The distinction between a notion of school science as building knowledge of the products of science rather than being concerned with the wider operation of the practices of science, has been at the nub of debate about school science practices for some years. Schwab (1962, 1965) famously described the traditional science curriculum as a 'rhetoric of conclusions' and argued for a science curriculum that educates students in what he called the *syntactical* as opposed to the *substantive* structure of the discipline: the way science ideas are posed, experiments are performed, and how data is converted into scientific knowledge.

This view, that school science should reflect the syntactical as well as the substantive structure of the discipline, underpins current emphases on inquiry curricula, and is well represented in the dimensions 'thinking and working scientifically' that appear in a range of contemporary science curricula. These distinctions align closely with Shulman's first two apprenticeships of thinking and performing. The third apprenticeship, dealing with identity, finds strong echoes in contemporary writing about student engagement with school science, and the values and dispositions underpinning school science education.

These three apprenticeships can be also aligned with the three dimensions of the newly formulated Australian Science Curriculum; Science as a way of knowing through inquiry, Science as a human endeavour, and Science as knowledge. Hence, it would seem that Shulman's analysis of professional education and signature pedagogies has strong echoes in contemporary writing in school science education. We will explore in this paper the possibility of enlisting Shulman's analysis to examine an innovative approach to school as a potential signature pedagogy.

The role of representation in teaching and learning science

For three years we have been engaged, in the RiLS project, with research in partnership with a small number of elementary and secondary school teachers to develop an approach to teaching and learning science that pays serious attention to working with the discursive practices of science and opening up the classroom to inquiry that balances the needs of representing the knowledge, the practices and the values of the scientific enterprise. We will argue that this representation – intensive pedagogy has embedded within it the pedagogies of uncertainty, engagement and formation that make it a candidate for a rich signature pedagogy for school science.

The RiLS research is grounded in a socio cultural perspective that views learning science at school as entailing students learning the literacies of a specific discourse community, involving a range of subject-specific and general representational tools to construct and justify evidence-based claims about the natural world (Ford & Forman 2006; Lemke 2004; Moje 2007). These literacies include the integration of knowledge, reasoning skills, and subject-specific procedures, enabling students to know, for example, why and how to use different representations to develop justifiable inferences from data, and know how to develop persuasive explanations for this community. There is growing acceptance that these representational tools are crucial epistemological resources for speculating, reasoning, contesting explanations, theory-building, and communicating. In this way science at its core involves a representational trail from the perceived or proposed attributes of real phenomena to theorised causal accounts, and that to understand the nature of science is to understand this process.

Research on the role of representation in scientific reasoning and inquiry has identified complex interplays between the objects of study, problem-solving, reasoning, and representational conventions, opportunities and choices. Researchers in classroom studies in this area (Carolan, Prain & Waldrup 2008; Cox, 1999; Greeno & Hall, 1997; Prain, Waldrup & Carolan 2007; diSessa 2004; Tytler Peterson & Prain 2006) have noted the importance of teacher and student negotiation of the meanings evident in verbal, visual, mathematical and gestural representations in science. They claimed that students benefited from multiple opportunities to explore, engage, elaborate and re-represent ongoing understandings in the same and different representations. Greeno and Hall (1997) argued that different forms of representation supported contrasting understanding of topics, and that students needed to explore the advantages and limitations of particular representations. Tytler, Peterson and Prain (2006) argued that this approach also had the merit of being consistent with science practices of meaning-making in the broader science community. It is this point that links what we have been doing in the RiLS project with the notion of a signature pedagogy.

In RiLS we have been working over three years with two grade 5/6 (age 10/11) primary teachers and two grade 7/8 (age 12/13) secondary teachers to plan and implement units of work which include a rich range of teacher and student-generated representations, investigative activities, and discussion. The focus is principally on student generation and negotiation of representations, and we have developed a set of pedagogical principles that unpack this approach, as a major outcome of the research. We will present two case studies to illustrate the nature of the intervention, and the way this pedagogy resonates with Shulman's (2005) analysis of professional education.

Case study: a primary school unit on animals in the classroom.

In this unit groups of students worked with invertebrates found in the school ground on questions they had a degree of control over. They used a series of investigative and modelling activities and had open access to the internet to identify and explore the characteristics of their animals. The major concepts covered in the unit included ecosystem, habitat, diversity of animal populations, animal structure and function and the adaptive purposes of behaviour. The two teachers combined their classes and co-taught the unit. Key characteristics of the sequence were a) an inquiry approach involving students asking questions, exploring and investigating, b) an explicit focus on representations and the use of multimodal representations, c) a focus on the methods used in science to study animals, and d) students generating their own representations in exploring ideas.

A series of moments is described below to capture the logic of the sequence:

1. A pre- test was administered which included exploration of students' conceptions of animal adaptation and also the nature of scientists' work in this area.
2. After preliminary group observations and discussion of school ground habitats, the idea of scientifically studying a habitat was introduced, and the need to develop quantitative data through sampling, measurement and representation. A sampling strategy was introduced and students taught techniques of sampling – the use of a quadrat. They discussed how best to approach their habitat. They then explored the habitat, sampling and drawing up representations using tables, graphs and other representations.
3. Children used the internet to identify animals which they had captured, and were taught the classification system. Each group worked on the production of a poster to communicate details of their habitat.
4. Children then conducted a guided investigation of invertebrate behaviour. Over two weeks groups worked on an exploration of the behaviour of a chosen invertebrate and the construction of a model to represent its movement. Over this period children were very active in exploring animals in their school, undertaking searches of the yard, and became expert in using the internet to identify what they found.

Research data included video recordings of classroom sessions and group activities, student workbooks, student and teacher interviews and field notes. The following data provide snapshots of students' experiences, understandings, and reasoning.

Figure 1 gives examples of the notebook entries of students as they observed their habitat and represented what was there. These representations are positioned as tools for observation of animal structure and function, and for conceptualising diversity. Figure 2 is from a poster entry of a girl who became 'quite fascinated in how they moved. She thought it was very cool that something could move without legs'.

Figure 1: Student notebook sketches

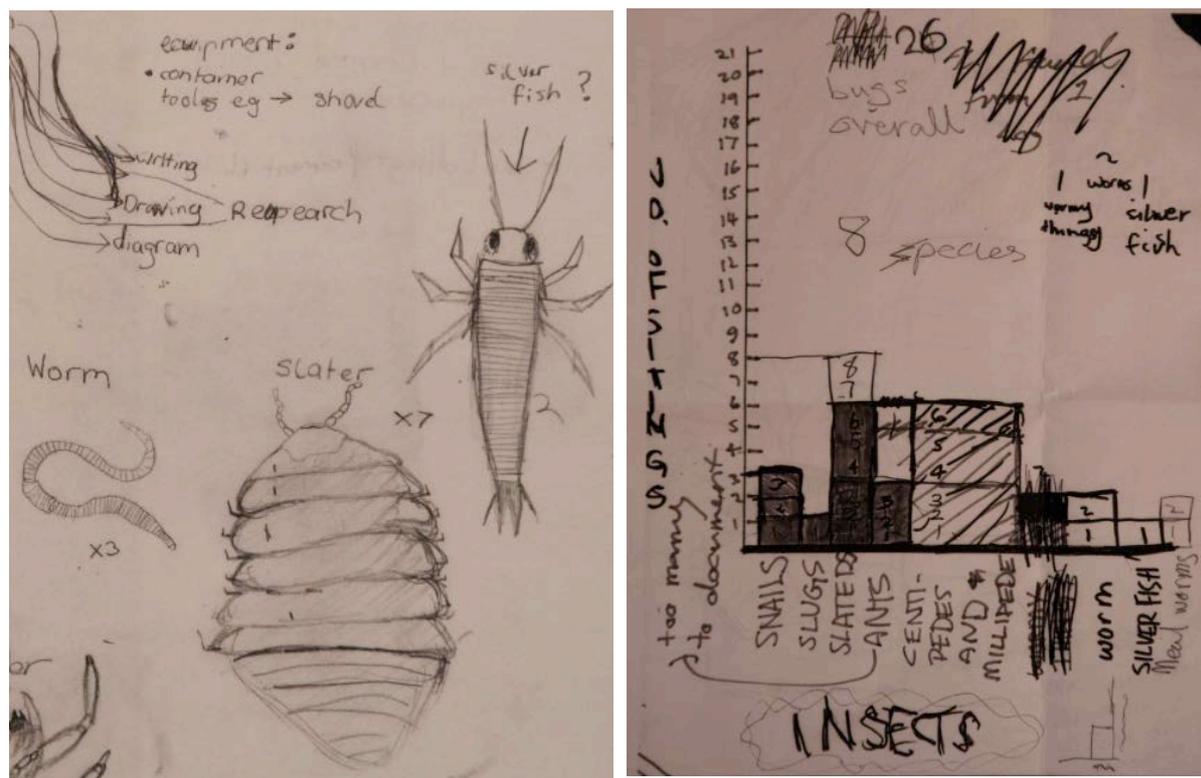
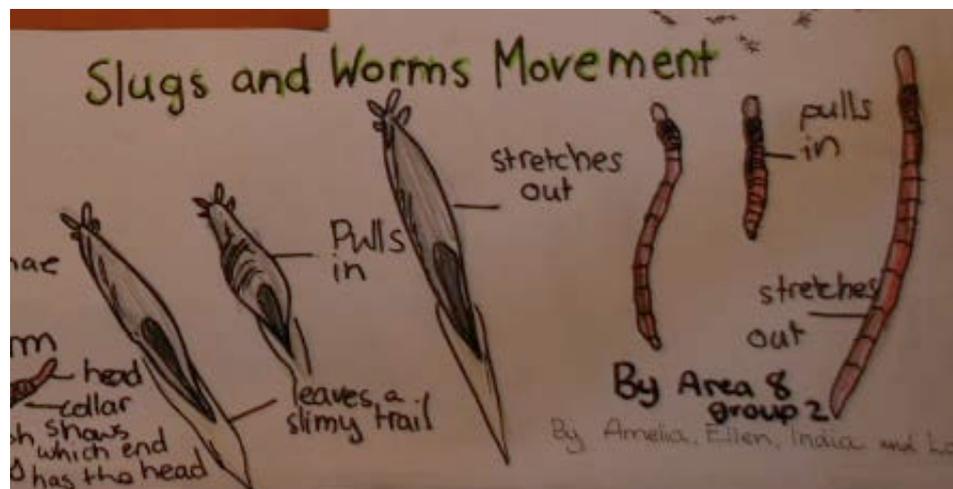


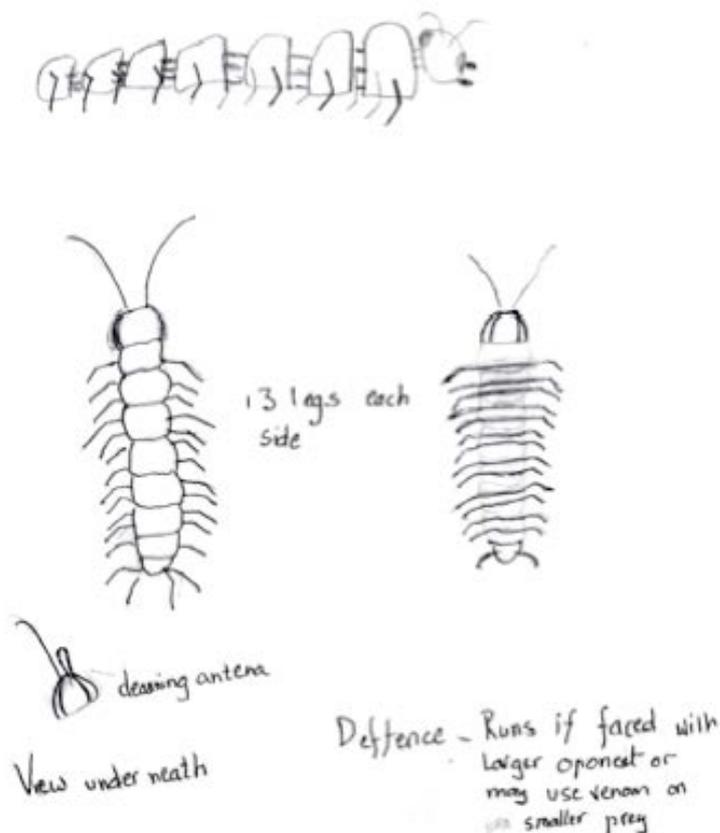
Figure 2. Iris's representation of slug and worm movement



Jesse and Paul are two students who took on the challenge of modelling centipede movement. Their 3D model demonstrated a close awareness of the nature of the jointed body and the sequence in which the legs moved. Figure 3 shows a series of drawings made by Jesse and Paul, of the arrangement of legs on their centipede, along with a close up of the animal cleaning its antenna with its mouthparts. These observations were later reflected in the constructed model, and in the verbal descriptions the boys made to the class. Figures 1 and 3 show similar 'ideas in progress'. Unlike many school science notebooks which are constrained by requirements of tidiness and the need for a polished final product, the notebooks for this unit were explicitly used as tools for thinking in preparing for later public

communications. Students used the books to jot down ideas and construct preliminary drawings that they later refined in their posters and models.

Figure 3: Centipede notebook entry



The drawing at the top of the page in Figure 3 represents a transition stage for their model design, showing separate body sections connected, in the final model, by ingeniously arranged strips of elastic (Figure 4) which helps them simulate the undulating movement of the centipede body. In interview, and in their presentation to the class, the two boys emphasised this swaying, undulating movement and the use of elastic to model this.

Their inference is very similar to recent findings regarding the movement of centipedes, showing that “the centipede was not passively bending as a result of its anatomy, but it was actively

trying to undulate” (Zimmer, 1994). Their very careful observation of the centipede’s movement and their inferences concerning the way the segments are mechanically linked, is evident in their drawings, their model, and in their verbal explanations and gestural representations of the movement. These representations are a critical resource for reasoning about the structures and behaviour of the animal, and for motivating them to pursue this reasoning. Such model based reasoning is a critically important aspect of the process of knowledge generation in science.

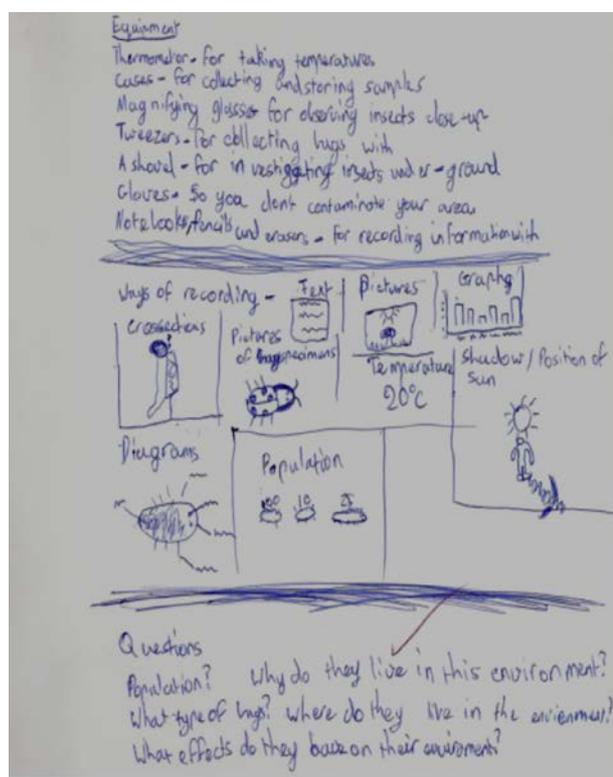
Figure 4: Jesse and Paul’s centipede showing the elastic arrangement.



The classroom was, in this unit, a highly active and generative environment in which student explorations increasingly arose naturally from their observations and internet searching. Through teacher input around representations and representational challenge and explicit negotiation of these, the classroom increasingly took on the form of a community of inquiry where students generated and explored questions in a self generating way. After a very naïve set of responses on the pre-test questions about how a scientist might study small animals in the forest, their post test responses concerning

equipment used, representations, and research questions concerning animals in the environment, were quite detailed and sophisticated.

Figure 5: Post test response on scientists studying small animals.



We have thus argued (Tytler, Haslam, Prain & Hubber 2009) that the focus on representational challenge and negotiation in this unit increased student engagement in learning, led to the production of new knowledge in ways not usual in science classrooms, and represented the discursive practices of science through which knowledge is generated. An important element of this was the interplay between teachers' discussion of the representations of science as a response to questions that arise about the environment, and students' generation of representations in exploratory tasks. In this way the representational focus served to constrain inquiry in productive ways. Treating science concepts as sets of representational practices rather than as end product verbal definitions allowed students to interact with canonical science knowledge in a flexible and generative way, responding to the particularities of phenomena and acknowledging the negotiated and conditional nature of the science. Further, through these practices students became committed to the exploration of phenomena and ideas and the generation of representations as claim in an explanatory chain of reasoning. The dispositions of curiosity, commitment to inquiry, and rigour in establishing ideas were all evident in students' behaviours.

Arguably, these characteristics are closely aligned with Shulman's three apprenticeships of knowledge, of expert practice, and of identity. We shall pursue this further after presenting the second case study.

Case study: a secondary school unit on force

This study describes two biology trained secondary teachers' adoption of a represent-focused introductory unit on forces to a class of Year 7 students. The unit was constrained around the canonical representations of force such as the explicit meaning given to such terms as *force* and *weight*, and protocols associated with the use of arrows in representing force within force

diagrams. The case study account given in this paper relates to the introductory lessons of the force unit where the scientific meaning of the term force and the arrow representation of force were introduced (Hubber, Tytler & Haslam 2010).

The teachers began the sequence by developing in students an understanding of the term *force*, assisting them to construct meaning for force through their everyday language. They 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*. The teachers 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 the teachers 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'. The students were then introduced to the scientific meaning of a force as a push or pull of one object onto another. The explicit link between the scientific meaning of *force* with everyday action words illustrated for the association of force with an action on an object rather than the commonly mistaken belief held by students that a force is a property of an object.

The teachers 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 6, were shared, discussed and evaluated within a whole class discussion.

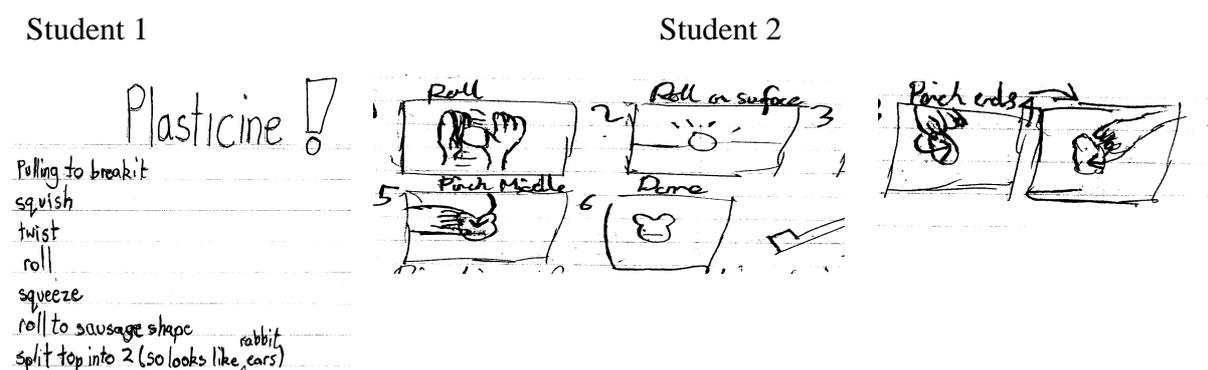


Figure 6: Student representations of manipulating plasticine

One representation which had a series of figures with sequenced annotation (Figure 7 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:

Teacher: 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.*

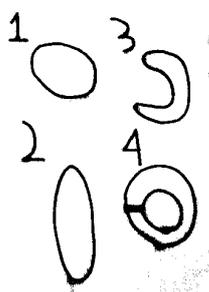


Image A

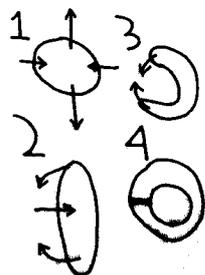


Image B

Figure 7: Reproduction of video images of John's representations

The teachers introduced force diagrams, which use the scientific convention of representing forces as arrows. They 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 7 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 8).

Student 1

Student 2

Student 3

Action	Arrow Diagram.
Rolling the Plasticine	
Squashing the Plasticine	
Tearing the Plasticine	

Figure 8: Students' use of arrows

The completion of this task produced different meanings of the use of arrows, which the teachers discussed with their 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.

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 9 Image A), (ii) students were given a piece of plasticine and asked to stretch 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 9 Image B).

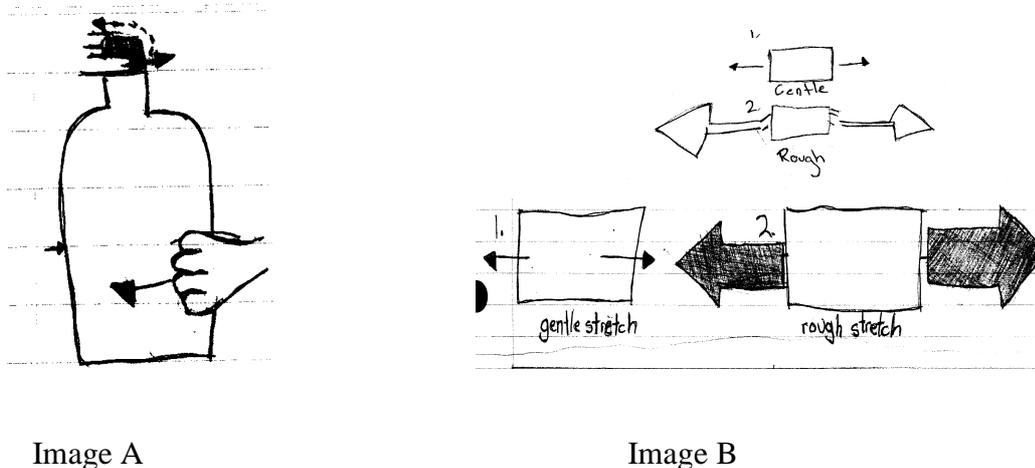


Figure 9: Student exploration of the arrow representation of force

Challenges for teachers of a representation-intensive pedagogy

The pedagogical principles arising from and underpinning the teaching and learning sequences involve:

1. *A clear conceptual focus in planning sequencing of work:* 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.
2. *Sequencing of representational challenges involving students generating representations to actively explore and make claims about phenomena:* Students need to be active and exploratory in generating, manipulating and refining representations. Student representations are coordinated with canonical representations, and there is a commitment to shared consideration and evaluation of representations.
3. *Explicit discussion of representations:* The teacher plays multiple roles, scaffolding the discussion to aim at student self assessment as a shared classroom process. The partial nature of any representation is acknowledged.
4. *Meaningful learning:* Attending to student engagement and interests, and providing strong perceptual/experiential contexts.

In previous years the teacher 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 one secondary teacher said:

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 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. One teacher described a change in her views thus, referring to a unit involving materials and particle representations:

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?

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

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 had 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'.

Alignment of this pedagogy with Shulman's framework

In terms of Shulman's three apprenticeships, taking the position that in some important sense these school students are being inducted into the professional practices of scientists, the pedagogy can be seen to bring these into a balance lacking in traditional science curricula where the emphasis is on knowledge reproduction, and where practices are represented these are mainly conceptualised as 'skills' such as observation, measurement and analysis, somewhat divorced from the main business of canonical knowledge construction.

In the pedagogy and epistemology represented in these cases, 'thinking' and 'performing' are mutually constituted in that the generation of representations to make sense of the natural world sits as both a practice and a way of thinking. The active knowledge construction and explicit negotiation of representations that accompanies the formation of a community of inquiry particularly evidenced in the first case is a reflection of the discursive practices of the discipline in ways that the more traditional conception of schooling in science as a knowledge apprenticeship is not. Even in traditional open inquiry approaches the processes of science can be separated from the knowledge building practices in unnatural ways. With regard to the apprenticeship of identity, the commitment of students to reason through representations to arrive at new insights, and the respect for evidence implied in the communal forms of representation, again are closely aligned with scientific practices. These students built their everyday classroom practice around a group commitment to seeking knowledge and building explanation that were grounded in canonical representations yet responsive to local contexts and problems.

Shulman's professional practice pedagogies also provide a useful framework through which to interpret the RiLS practices. The *pedagogies of uncertainty* notion captures the ways in

which students are challenged to interpret situations for which there are a variety of possible responses, resulting in a dependence of the teaching sequence on the student generated representations and the teacher adaptations of these. The direction that the teaching proceeds are not entirely pre-determined. The *pedagogies of engagement* notion was evidenced in the way students committed to generating ideas and explanations. Teachers in all cases were struck by a new depth in student learning and the sustained nature of discussion round representations.

The *pedagogies of formation* notion captures the way in which this representational focus engaged students in generating representations to pursue genuine questions that were meaningful to them. By operating in a community of inquiry, students are developing those commitments to rational argument, respect for evidence, and imaginative problem solving that are central to scientific practice.

Conclusion

We have argued in this paper that there are aspects of Shulman's signature pedagogical analysis that can be applied to school science education to provide a framework to explore the efficacy of a representation-intensive pedagogy and its potential as a signature pedagogy. The argument has hinged around the capacity of the pedagogy to bring together knowledge and practice and identity in a coherent way. The pedagogy is framed within an epistemology that emphasises the active generation of knowledge grounded in local context, and challenge and support in the face of uncertainty. In this sense we argue that it significantly represents the knowledge production practices of science in ways that traditional or even standard inquiry and conceptual change approaches do not.

Shulman's analysis, in emphasising a shift away from thinking of professional expertise in terms of declarative knowledge, towards a more integrated and significant view of the person in practice, thus has the capacity to help frame and support contemporary thinking about school science curriculum reform.

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