Learning Junior Secondary Science through Multi-Modal Representations

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Abstract

There is growing recognition that learning science in school entails understanding and linking verbal, visual and mathematical modes to develop knowledge of scientific concepts and processes. However, students face considerable challenges in engaging effectively with these literacies of science as they interpret and construct scientific texts. Our paper reports on two case studies on the topics of the particle theory of matter in Year 7, and force in Year 8. We aimed to identify (a) students' understandings of, and capacity to link, different representational modes to develop conceptual knowledge, and (b) teachers' perceptions of, and strategies to support, learning through this interlocking modal focus. Analyzed qualitative data included work samples, and focus-group interviews, as well as observations and interviews with participant teachers. The findings indicated that this multi-modal focus posed significant demands on learners, but had the potential to enable effective learning.

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Introduction

There is growing agreement in science education research that learning science entails learning the representational practices of this subject, including the reasoning processes, habits of mind, and rationale that underpin these practices. Science literacy is now understood as knowing how to interpret and construct these literacies of science (Norris & Phillips, 2003). From this perspective, learning scientific concepts and methods entails understanding and conceptually linking the purpose-built multiple and multi-modal representations of this domain (Ainsworth, 1999; 2006; Australian Academy of Science, 2005; Lemke, 2004; Gee, 2004; Russell & McGuigan, 2001). 'Multiple' refers to the practice of re-representing the same concept through different forms, including verbal, graphic and numerical modes, as well as repeated student exposures to the same concept. 'Multi-modal' refers to the linked use in science discourse of different modes to represent scientific reasoning and findings.

Given the increased use of new technologies to conduct and represent scientific activity in the science community and beyond, students' acquisition of this complex representational knowledge now poses very large challenges for effective classroom teaching and learning strategies. A key issue is to develop students' multi-modal thinking and reasoning in learning contexts that are consistent with current general principles of effective pedagogy for science learning. These principles emphasize the importance of catering for students' individual learning needs, preferences, and interests, and drawing effectively on students' current visual, verbal and numerical representational resources in acquiring the new literacies of science. At the same time, students need to be engaged actively with explanatory ideas and evidence that they can connect to real purposes and practices in their everyday worlds (Tytler 2003). This implies that student engagement with the key issue of how to represent science ideas and processes requires many iterations that are meaningfully contextualized and draw upon and expand their current repertoire of ways of showing what they know.

Much recent research on learning with representations generally, and in science in particular, has focused on identifying key design features of effective representations that promote successful student interpretation and learning (Ainsworth,1999, 2006; Schnotz & Bannert, 2003). The governing logic of this approach is that felicitous design features in representations can optimize student learning capacities. However, the highly complex nature of multiple representation environments poses many intractable questions for effective design. As noted by Ainsworth (2006) and others, design researchers are beginning to wrestle with many issues including the following typical questions. What number, type, style, and sequence of representations will maximize learning outcomes for different students? To what extent does brevity or redundancy of information in and across representations enhance learning, and under what conditions? To what extent do dynamic representations, such as spoken voice, animation, and dynamic graphs, enhance or impede interpretation of represented information when contrasted with static representations, and under what conditions? Are particular concepts better matched to particular representational modes, and how does the age and background knowledge of students affect learning outcomes? To what extent does interpretive constraint in a representation, such as graphic simplicity, help or hinder student understanding, and under what conditions? To what extent should science learning be focused only on domain-specific representations such as time graphs or cross-sections, or can learning be enhanced by including more domain-general approaches, such as visual displays and posters, and under what conditions and with what age or cultural groups might this mix be effective?

While various empirical studies have attempted to isolate and assess these different design options and sequences, and with mixed results, other research, including our own, has focused more on factors affecting students' own construction of scientific representations within mainstream classroom programs (diSessa, 2004; Prain & Waldrip, 2006; Russell and McGuigan, 2001; Tytler, Peterson & Prain, 2006). This research acknowledges that students must learn how to interpret science texts to achieve science literacy, but emphasizes a strong reciprocity between interpreting and constructing these representations. In constructing a science representation students are also involved in interpreting their own construction, its coherence and adequacy in representing their intentions and ideas, and the extent to which it will make sense to others, as well as its fit with the appropriate conventions for this kind of representation in science. We would also assert that students often need considerable practice in negotiating the construction of representational options, in order to understand in any depth the function and design of representational practices in science discourse. Students need to understand modal diversity in representations of science concepts and processes, be able to translate different modes into one another, as well as understand their co-ordinated use in representing scientific knowledge. While different classifications of these modes have been proposed, there is broad general agreement that these forms include such categories as descriptive (verbal, graphic, tabular), experimental, mathematical, figurative (pictorial, analogous and metaphoric) and kinaesthetic or embodied gestural understandings or representations of the same concept or process. There is increasing recognition that developing students' capacities to interpret and construct these complex science texts poses significant cognitive and pedagogical challenges.

In this paper we focus on case studies of teacher and student understandings and practices in engaging with multiple and multi-modal representations of the topics of force in Year 8, and changes to matter in Year 7 in mainstream classroom settings. As suggested above, our approach focussed mainly on lesson sequences where students were expected to construct representations of their own science investigations, drawing on their current representational resources supplemented by teacher guidance. We first review the theoretical framework and literature that guided our study's orientation.

Theoretical Framework of Study

The study was framed by current theoretical accounts of the nature of science discourse, learning as re-representation, and effective pedagogical conditions to promote student learning. These perspectives are viewed as compatible in that they link theories of science as a subject to how science can be learnt effectively, what should count as this learning, and broad socio-cultural factors affecting learning outcomes.

There is growing recognition that the discipline of science should be understood historically as the development and integration of multi-modal discourses (Lemke, 2004; Halliday & Martin, 1993; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Norris and Phillips, 2003), where different modes serve different needs in relation to recording and integrating various kinds of scientific inquiry and reasoning. In this way, mathematical, verbal and graphic modes have been used individually and in coordinated ways to represent the knowledge claims of science discourse, with more recent technology-mediated representations of science consistent with, rather than a deviation from, this evolution of science as a discipline. By implication, students in the middle years of schooling need to learn about the multi-modal nature of the representation of scientific inquiry, and the different modes in which the same concepts in science can be represented as part of students' general development of science literacy.

Complementing this epistemic viewpoint, Ainsworth (1999) asserted that to learn from engaging with multiple representations of science concepts, students needed to be able to (a) understand the codes and signifiers in a representation, (b) understand the links between the representation and the target concept or process, (c) translate key features of the concept across representations, and (d) know which features to emphasise in designing their own representations. In this context, 'translation' means being able to recognise conceptual links between representations or invariant conceptual features across representations. Ainsworth (1999) posited that learner engagement with representations could support learning in three ways. These were (a) when the new representation complemented past understanding by confirming past knowledge, (b) when the new representation constrained interpretation by limiting the learner focus on key conceptual features, or (c) where the different representations enabled learners to identify an underlying concept or abstraction across modes or within the same mode of representation. This perspective is consistent with another account in cognitive science of the nature of learning as 're-representation' (Karmiloff-Smith, 1992). From this perspective, as noted by Russell and McGuigan (2001, p. 600), the developmental processes of student understanding involve the 're-coding of representations', implying that conceptual growth entails a process of re-representation, where learners generate and transform 'representations which are stored in different modalities, with meta-cognitive "explication" mediated by linguistic processes' (p. 600). From this perspective, learners use talk and other forms of representation to re-represent three-and two-dimensional experiences and records of understanding to clarify science concepts and procedures. This activity is also consistent with Paivio's (1986) theoretical account of the function and value of multiple coding in learning.

Our approach was also guided by current accounts of effective classroom pedagogy. A focus on representational diversity is consistent with recent calls for more student-responsive approaches to learning in the middle years of schooling (Gough, Beeson, Tytler, Waldrip, & Sharpley, 2002). Such an approach is viewed as likely to engage learners more than a traditional focus on restricted forms of representing scientific ideas evident in text books or usual classroom practices. This orientation is also consistent with recent research findings by Tytler and Waldrip (2002) that students learn most effectively in science, and engage more with the subject, where they are challenged to develop meaningful understandings, where individual learning needs and preferences are catered for, where a range of assessment tasks are used, where the nature of science is represented in its social, personal and technological dimensions, and where links are made between the classroom programme and the local and broader community that emphasise the broad relevance and social and cultural implications of science.

We considered that these broad theoretical orientations, in combination, provided an analytical framework for assessing factors affecting student learning in relation to representational choices and understandings.

Recent Research on multi-modal representations of concepts in learning science

Various studies have been conducted on student learning through interpreting and constructing different representational modes, including in primary classrooms (Russell and McGuigan, 2001) and in senior secondary physics (Dolin, 2001), with the use of some forms of representation researched in depth, (Glynn & Takahashi, 1998), such as the use of analogies for learning science (Coll & Treagust, 2001) and the role of scientific models in this process (Treagust, Chittleborough, & Mamiala, 2002). In asking primary school students to represent the same concept in different modes, Russell and McGuigan (2001) argued that the re-coding activity enabled learners to refine and make more explicit their understandings. In their classroom programme both student and teachers generated various representations of target concepts, and knowledge construction was viewed as the process of making and transforming these different representational modes, as they scaffolded their understandings in relation to their perceptions of the real world. Dolin (2001) noted that senior secondary physics students achieved enhanced understanding of concepts in physics when they attempted to translate different representational modes into one another in that subject.

Other researchers, such as Gobert and Clement (1999, p. 49-50), and van Meter (2001) have claimed that some modes may be more supportive of student learning than others, noting that students can 'draw to learn' effectively, where the visual media affords 'specific advantages over the textual media'. More recently, research in this area has focused variously on students' construction of self-explanation diagrams (Ainsworth and Iacovides, 2005), understanding concepts across multiple representations in different topics (Parnafes, 2005; Tytler, Peterson & Prain, 2006), and the role of visualization in textual interpretation (Florax & Ploetzner, 2005). Researchers in this field have also acknowledged the challenges learners face in constructing successful representations of science concepts. Ainsworth (2006, p. 186) noted that students needed to know how science representations encode information, including interpretive procedures, or 'operators'. They also needed to know how to construct an appropriate representation, in terms of its fit with the conventions of science discourse, including brevity, compactness, absence of ambiguity, and structural coherence, or systematicity. According to diSessa (2004, p. 298), "students start with a rich pool of representational competence" based on their past experiences with interpreting visual texts, and are 'strikingly good at … designing representations". He considered therefore that "rich and engaging classroom activities are relatively easy to foster " (p. 298) that are highly motivating for learners. However, like Gee (2004), Unsworth (2001) and others, he acknowledges that students also need to learn about the "sanctioned representations" (p. 294) of science, and justifiable strategies for their interpretation.

In a study of teacher perceptions in using multi-modal representations to support student learning in science, Prain & Waldrip (2005) noted that the teachers considered this focus could promote deeper learning, but was not easily accommodated within a tightly structured sequential learning process. Rather, teachers needed to respond flexibly to emerging learning opportunities and diverse student needs and capabilities. To succeed with this approach, students also needed to be familiar with the nature of the representational conventions in different modes in order to represent and translate concepts across modes. The teachers were aware that representations differed in their degree of abstractedness from, or visual similarity to the target concept, and that these differences posed further challenges for learners. While the teachers did not focus explicitly on these differences within individual representational modes with students, as recommended by Jewitt and Kress (2003), the teachers saw these differences as indicative of further complexities in choosing appropriate modes to enhance learning for students with different capabilities.

In summary, past research into an explicit focus on student engagement with specific representational modes and tasks has suggested the value and potential of this approach for promoting learning and for engaging a broad range of learners. Our study sought to investigate current teacher and student practices in relation to this negotiation of representational meanings. We also considered that this focus on opportunities for students to use multiple and multi-modal representations in the transitional years from primary to secondary education could meet the conditions for effective science learning, as outlined above by Tytler and Waldrip (2002).

Aims of Study, Research Methods and Context of Study

In this study we aimed to identify:

1. students' understandings of, and capacity to link, different representational modes to develop conceptual knowledge, and
2. teachers' perceptions of, and strategies to support, learning through this interlocking modal focus.

The study followed a mixed methods approach entailing collection and analysis of qualitative data (Cresswell, Tashakkori, Jensen & Shapley, 2003), including triangulation of different data sources to achieve convergence of results (Denzin & Lincoln, 1995). The research also included a case study approach (Merriam, 1998) that aimed to identify teacher and student perceptions in engaging with different representational modes. Initially, eight teachers were surveyed about their planning and usage of different representational modes. The survey preface indicated that "there is growing recognition that ideas can be represented in more than one way. These representational modes might include diagrams, cartoons, newspaper articles, photographs, written text, computer programs, images, models, analogies, drama, roleplay, acting out a process, data tabulations, numerical calculations, graphing, and posters". Teachers were asked about how they chose and used different representational modes to explain ideas, and what modes they might get students to make or use to engage with or show they understood ideas. The teachers were not told of modes the researchers might prefer. The surveys were analysed for patterns of common themes and differences in approach or emphasis.

From this initial survey, two teachers and their classes were selected for more intensive study of classroom practice. In this phase, lessons were observed, and interviews with teachers allowed insights into different pedagogic approaches from which it was possible to discern their views of learning and knowledge in relation to diverse modes of representation.

In this paper we report on two case studies, a unit on change of matter in year 7 taught by Meg, a teacher with over 20 years science teaching experience, and a unit on force in Year 8 taught by Barry, a secondary science teacher with over 30 years teaching experience. These units were taught in two regional Australian secondary state schools with students with predominantly low socio-economic profiles. Both units ran for eight weeks. Each teacher had participated in an in-service program with the researchers, that focused on the use of diverse representations, such as concept cartoons, and software programs to elicit and frame students' understanding of science topics. In devising the selection of resources and student tasks for each unit, the teachers collaborated with the researchers. Students' views and practices were also ascertained through classroom observations, surveys and transcription of group interviews of four students in Barry's class, four students twice in Meg's class. An earlier paper summarizes the teacher survey and some classroom observations (see Prain & Waldrip, 2005). Here we focus on both student and teacher perspectives and practices in the two classes studied.

Classroom Programs: The Unit on Change of Matter

Meg's main goal in this unit was for students to learn to recognize and utilize the application of a particle theory view of matter to a new situation/observation. She organized the unit into two phases, with the first five weeks including lesson content and strategies previously used by the teacher to develop student understanding of the application of 'Particle Theory' to the explanation of matter, its states, their properties, and transitions between states. In the last three weeks of the unit students were expected to use audiovisual hardware and software to develop a presentation linking different modal representations of particle theory to explain their observations of a laboratory demonstration. This was the major assessment task in conjunction with a standard test and several formative assessments during the teaching phase. Students had three 45 minute periods per week with two of these periods joined as a 'double'. Over the assessment phase, an extra two periods were utilized to allow sufficient access to ICT resources. The school Middle Years' structure encouraged teachers to teach one group for more than one subject area. The class was taught by the teacher for both science and mathematics. This allowed some flexibility in the provision of lessons and transfer of skills such as the use of spreadsheet software during the unit.

Meg considered the group "a strong class", with a balanced mix of girls and boys. In planning the assessment phase, Meg thought that sixty percent of the students were capable of attempting a conceptually demanding task. These were mostly girls who were subsequently observed to display very good communication, planning and organizational skills. Throughout the unit the particulate nature of matter was emphasized both verbally and by drawing student attention to diagrammatic representations on the board, and Meg also demonstrated the behaviour of particles using marbles on an overhead projector. Early in the unit students participated in a role-play enacting particle behaviour, such as the degree of attraction between particles, for one of the states of matter.

Meg began the lesson sequence with board notes for students to record in their books detailed notes on the scientific (textbook) understanding of matter, its states, their properties and transitions, and she introduced particle theory as an explanatory framework. This was accompanied by a 'brainstorm' activity where the students constructed a table of examples under the headings Solids, Liquids and Gases. The next lesson began with a practical investigation sourced from a Year 7 Science text book (Science Quest 1 Section 3.1). This involved students making observations of the properties of solids, liquids and gases and recording these in a table. The students also completed a 'silent card shuffle' activity where sets of representations (particle diagrams and written descriptions) matching each of the states were identified by students and pasted in their exercise books. In the next lesson students collected objects and recorded their physical properties. Meg believed that this activity was provided to give the students opportunity to begin using 'appropriate terms'. The students also watched a video titled 'What Matter is Made Of' and filled out a corresponding worksheet.

A single lesson was now dedicated to student observations of situations involving diffusion in different media. These were potassium permanganate crystals in water, bicarb soda in a Petri dish and eucalyptus oil scent in air. The teacher used this in the context of class discussion to emphasize verbally that particles were actually moving and so defined the new term and concept of 'diffusion'. The learning sequence now turned to 'change of state'. Students set up a situation where water was boiled in a beaker and condensed a 'cloud' below an ice-filled watch-glass set on top. Students recorded a labelled diagram of the apparatus and their observations. They then completed a picture of the "water cycle in nature" by labelling with terms such as 'evaporation' from a list provided.

Students then watched a video in the next lesson and completed a word 'craze' where they filled in the gaps in sentences with words provided, and answered questions regarding condensation and matched terms. In the next lesson students completed a comprehension activity where students read a description of the particle theory defining new terms and then answered questions requiring them to "apply particle theory to explain properties" (of matter). Students then used a lesson to complete activities from an interactive computer software program 'Professor McClutcheon' which the teacher noted "explains concepts well" including "visualizing particles". This "reinforcement" activity required students to apply particle theory in order to work through the program. The students were provided with concept cartoons with the speech balloons blanked out. These portrayed two situations involving water boiling and students were required to complete the speech balloons to explain the situation to assess if they would employ the particle model without prompting. A practical skills activity followed where the particulate nature of the substances was not emphasized. The mass and volume of small objects were measured and entered into a software spreadsheet to determine density. The end of the teaching phase was punctuated by a 'standard' paper-based written test.

The learning/assessment task required students to apply a particle theory to a new situation using common laboratory apparatus, and providing an extended explanation via a multi-modal presentation. The choice of assessment aimed to facilitate a motivational function as well as provide adequate time for students to reflect on possible explanations in light of their recent learning. The students were introduced to different pieces of laboratory apparatus designed to provide examples of heat transfer, expansion, air pressure (vacuum) and diffusion. They were provided with a lesson to familiarize themselves with the correct operation of the apparatus and to make observations of its function and purpose.

They were then shown two examples of multi-modal audiovisual presentations made by older and younger students to explain concepts and processes. The former explained the approach to and solution of a mathematical problem, whilst the latter was a primary explanation of a thermometer. They were then encouraged to consider what combination of mode, content and explanation they would need to use to explain their observations of the apparatus previously explored. They were also encouraged to reflect on their recent learning to include a 'theoretical' explanation in their presentation. The students subsequently began collecting video and still images of their apparatus and developing verbal accounts. In the following lesson the student group was tutored in the use of software to facilitate the construction of a multi-modal presentation with a simple non-scientific example provided by the researcher. They were observed to have success with the use of the software, quickly demonstrating effective use of functions. The students then had approximately three lessons to develop their presentations with access to their apparatus, computer facilities, and video equipment.

Classroom Programs: The Unit on Force

This unit spanned approximately 8 weeks although with interruptions was described by the teacher as “4 weeks’ work” because only approximately 14 periods of Science were taught. Students had three 45 minute periods per week with two periods of these joined as a ‘double’. Barry’s goal for the unit was for students to understand key concepts about force in relation to simple machines. The classroom contained computers which the students were able to use at their own initiation or the teacher’s for learning/assessment activities. With the introduction of the new integrated curriculum in Victorian schools, the program structure focused on year level teams with paired form groups with two principal teachers teaching core subjects. The class was taught by the teacher for both Science (under the title of Trans-Disciplinary Studies) and Mathematics. This allowed flexibility in the provision of lessons and transfer of skills such as the use of spreadsheet graphing software during the unit. Barry considered the class as “better than average” without a “big bottom end” of struggling or disengaged students.

Barry introduced the topic over a few periods by watching the Honda Motor Car advertisement (http://www.youtube.com/watch?v=g2VCfOC69j) and looking at the work of U.S cartoonist Rube Goldberg. The students were then encouraged to produce their own “Goldberg style” cartoon. This was used by the teacher to facilitate “one to one discussion” with students and to encourage them “to look at movement and force ”. Some students requested to produce their ‘poster’ by animating pictures using PowerPoint. The teacher later utilized this skill base in other learning and assessment tasks. He provided a number of worksheets to the students during the unit and instructed them on the recognition of simple machines, associated terminology (fulcrum, load, inclined plane etc), their taxonomy (class of levers) as well as the identification and labelling of direction and extent of forces and motions.

The students attempted one of a range of practical activities covering each of the major simple machines and focusing on the central concept of work. This was structured as a “jigsaw” activity designed so that individuals made measurements and observations of force and distance moved in a particular simple machine. To facilitate student re-representation of the work concept they were asked to record their learning on a worksheet in a table, written sentence, labelled diagram and mathematical equation. The teacher observed that this activity did not “work as well as I’d like it to”, citing problems with students following some of the practical instructions and with the need for greater scaffolding prior to the task.

The class watched and responded to a number of video presentations (Stansfield & Boiteau, 1981) to introduce and reinforce simple machine, mechanical advantage and work concepts. Students had access to the internet via classroom computers which allowed access to simple machine websites to reinforce concepts previously covered. Sites included:

http://www.mos.org/sln/Leonardo/GadgetAnatomy.html Recognition of simple machines (in complex machines) activity –10 minutes;

http://www.mikids.com/Smachines.htm Naming simple machines e.g. propeller as an inclined plane. –15 minutes;

http://www.edheads.org/activities/odd_machine/index.htm Covers some forces revision as well as identifying and using simple machines. –15 minutes.

The whole class also had a session using the interactive website *Aspire – Simple and Complex Machines* (http://sunshine.chpc.utah.edu/javalabs/java12/machine/index.htm). This enabled students to conduct virtual experiments measuring force and distance for simple machines (wedges, lever, ramps, pulleys, inclined planes, screws, wheels and axles). Students then entered these measurements in a spreadsheet to calculate work done and note the conservation of work in each example.

Barry aimed to assess students' theoretical and applied (pertaining to actual "measurements") understanding of the simple machines concepts though two pieces of assessment. In pairs, students were provided with a word list which, after watching a general machine video (Beeston & Maude, 1997), they used to construct a sentence or sentences describing or explaining some aspect of simple machines. These were assessed for individual understanding of simple machine concepts such as the conservation of work. Following this, students were provided with an example of a compound machine such as a can opener, shifting spanner, or lever-action cork remover. They were instructed to observe closely the machine to identify each feature, how these worked, and measure the direction and extent of motions and forces to determine the mechanical advantage. They were then provided with an option of presentation formats to report and explain their observations, either, according to their preference, as a poster or using PowerPoint to animate diagrams.

Findings

As the summary accounts of each lesson sequence above make clear, students in each class participated in a diverse range of interpretations and constructions of multiple and multi-modal representations of science concepts and processes. These included group and whole class talk about different aspects of the topic, interpreting teacher notes and diagrams, re-representing three-dimensional practical activities in two-dimensional formats, making sense of video and other resources used to supplement classroom activities, participating in virtual web-based experiments using tables and graphs, interpreting in written language key concepts in a concept cartoon scenario, enacting understanding of concepts with physical actions and roleplay, and constructing their own multi-modal two-dimensional representations of practical investigations. The interview data, observations and examples of students' work, were analysed to identify major episodes of interactions; fine-grain analysis of interview transcripts within these interactions; and recomposing these smaller analyses into patterns to create assertions as to what are students' perceptions of the roles, forms and interplay between different multimodal representations in science classes. These assertions form the basis for identifying conditions and strategies that maximise the learning outcomes of this approach. Given also the diversity of student background knowledge and interests in science, it is very difficult to ascribe particular learning outcomes to specific representational work within these mainstream classroom programs. Clearly, too, the teachers in each lesson sequence understood effective learning opportunities as a re-iterative process whereby students re-visited negotiation of the meaning of concepts in different representational forms and across different contexts.

In the light of these complexities in the learning environment in relation to representation, and diverse contextual factors influencing learning outcomes, our reporting of findings focuses on indicative general teacher and student perceptions of learning effects rather than claims of tight causal links between an example of a representational construction or interpretation and a learning outcome. We draw on two specific examples of student work, as well as student and teacher reflective comments on this work, as indicative of general effects of a representational focus rather than as conclusive evidence of causal effects.

In the first student work example, three Year 7 students produced a Powerpoint to represent diffusion of particles of scent throughout the classroom. At this year level, students were expected to begin to use a simple particle model to relate the properties, behaviours and uses of substances to their basic material structure. In the Powerpoint, the students have clearly adopted a particulate view of matter as displayed by the diagrammatic representation both in the first and fourth slides. The latter also demonstrates that the students have a sound basic understanding of the properties of a gas, including particles filling a closed container, and the random spread of particles. The written component of the description reflects recognition of the importance and action of the role of forces between particles in determining behaviour of the substance, where weak force means low attraction so particles spread out as a gas. It also shows an understanding of diffusion as occurring ostensibly from areas of higher to lower concentration until equilibrium is reached. The written component could be seen to imply but not directly express the idea that the smell is the gas particles. The students may still consider that the non-particulate smell is somehow being carried by the gas particles and this may warrant further probing, perhaps verbally and/or by encouraging the students to refine further their explanation to achieve clarity of expression. The written account also mentions liquid evaporating but does not reflect this in the diagrams presented, and expansion here should further reveal the students' deeper understanding.

In the second work example, two Year 8 students produced a Powerpoint of a corkscrew opener to show understanding of force. In this unit students were expected to recognize and explain how mechanical systems can direct and modify force and motion. They were expected to identify simple machines such as pulleys, gears, levers and inclined planes, and describe their action in producing a mechanical advantage. The students in this work example have been able to break a compound machine down clearly into its component simple machines through investigation of its actions. They have been able to represent them both separately and in combination through clever use of animation showing their action in context. The students through their measurements have been able to recognize the source of the mechanical advantage of the machine as being gained at the expense of greater movement of the lever compared with the cork. Later they demonstrate an understanding of the mathematical relationship between effort and load and their distance from the pivot point for a lever. The students have not overtly expressed the benefit gained from the machines, such as the idea that less force is needed to remove the cork or top, nor mentioned mechanical advantage or the concept of work done, despite having covered these in previous learning activities. Ideally for a summative assessment this recognition or understanding should be expressed. However, Barry considered that the students understood this, based on his informal observations during class.

Student views on multiple representations

Meg and Barry had not focused on making explicit to their students why each unit entailed making multiple representations as a major part of assessment. As a consequence, when asked about this in subsequent interviews, the students did not have a strong sense of the purpose or rationale for this approach. However, in these interviews, students gave thoughtful accounts of how they constructed their representations, factors that affected their decision-making, and some sense of how this approach supported their learning. Students commented on the value of the role play in Meg's class, crediting this activity with giving them "a better idea of what they (the written descriptions) meant", and also noting that "doing it made you think about it - about what you are doing". They also commented on the 'silent card shuffle' activity where they identified sets of representations (particle diagrams and written descriptions) matching each of the states and pasting them in their exercise books. They saw this work as valuable in consolidating their understanding.

In the following interview segment, a Year 7 student in Meg's class explained the process her group used to construct the Powerpoint animation to represent the diffusion of scent as particles throughout the classroom:

Student: *With ours (the diffusion of scent) you couldn't take many pictures because you obviously can't take pictures of particles, so we just got the little circles and made shapes to show the jar thing and how they travel if they are let out.*

Researcher: *Did you start out with your pictures and then go to the words?*

S: *We started off with words and then we did the front heading (first slide) which had all the particles moving around, and then we did writing, and at the end Lauren thought of that picture which was really good and explained it more.*

R: *So with you, personally, what did you start thinking about, now that you have got this feeling about everything being particles. Were you seeing it as a picture or were you thinking of it as a spoken description?*

S: *Yeah, I was thinking of it, visualizing it, but with the computer it really helped with all the pictures.*

R: *So was it hard to go from that to the written part?*

S: *Yes, it was so hard because … all the other people got to do experiments where you could see actually what was happening, but with ours you could just sit it there (the jar of scent) and you had to wait for the smell to travel and it was really, really hard because you can't take pictures or videotape it.*

While these comments are mainly descriptive of the choices involved in the construction process, they point to some deeper understanding of the need to change representations to show understanding of the idea of particles in this particular context. In her responses the student recognized that the animation had to re-represent a process that could not use other obvious forms of evidence. In commenting further, she said "We thought we'd just have to write about it so we got the idea…of people putting up their hands when they could smell it (diffusing across the room) so we made a video of that".

This student also thought that the task would be easier if the teacher provided more explicit guidance on how to structure the representation. While the class was shown some unrelated examples of student-produced multi-modal texts, the students wanted additional guidance in "how do we do that", including both technical understanding for making the product, and advice on format and focus in linking modes, even though their products demonstrated a capacity to make modal linkages. In the case of the diffusion animation, visual and written texts were linked, and the students demonstrated knowledge of how to represent a process and passage of time through a three-step set of diagrams. The students who made the multi-modal representation of the animation of forces involved in the operation of a corkscrew opener linked visual text, labelled diagrams, measurement of force, arrows to indicate the direction of force, and animation of the stages of the process. They also used the convention of representing the corkscrew in a frontal perspective level with the viewer, thus emphasizing the objectivity of the representation. They also simplified the representation to highlight key aspects of the machine in a style typical of traditional labeled diagrams in science texts. In these ways both groups of student demonstrated knowledge of some of the conventions and aims of science texts relating to clarity and coherence of the representation.

In a follow-up conversation with a student from Barry's class, one of the two boys who worked on the Powerpoint of the corkscrew opener's action, the researcher asked what the student tackled first in constructing this representation:

Student: *Oh, the diagrams.*

Researcher: *And why was that?*

S: *Well I like to have a visual type thing to see it.*

R: *So did you have to talk much about your diagrams?*

S: *Just debating it, on how sort of accurate we were going to make it.*

R: *When you went from transferring it from your diagram to your writing was that hard?*

S: *When we first started it (examining the tool) I wrote down stuff in my book, just taking notes about what each thing did and we basically elaborated on that.*

R: *Did you have much discussion about what you wrote down because it seemed from before (when viewing the presentation) you picked it up and said that your partner might have written something down wrong? Why was it important for you that he might have changed that to make it a little bit different?*

S: *I'm kind of an individual kind of worker and then it's good to work with someone. It's all right, I mean it's both of our things (work).*

R: *So you had to negotiate what the end product was?*

S: *Yep.*

R: *Did you have to discuss whether it was right or wrong, the different things you put in there?*

S: *Oh yes. Just some of the things Chris pointed out that I hadn't put in that we needed to point out.*

These responses indicate the student is aware of the need for text and diagrams to cohere, and the need to check with a partner about the accuracy and clarity of the product. This student also commented that having to explain the text to a partner and other students helped him learn because "you have to learn more about it if you don't know enough about it".

A group of students in Meg's class were asked why she encouraged them to use a software program for their assessment task that enabled them to represent different modes such as video, diagrams, written text, and graphs on the same screen. Their responses indicated that they saw value for their learning in constructing this text:

S2: *Probably because we have to explain it ourselves and instead of using really big words to explain we have to use little ones that you can understand.*

S3: *Yeah, we have to think about it ourselves, like you can help us do it, but we have to try and do it ourselves and think about it.*

Researcher*: So why didn't we just give you a piece of blank paper and say write about it? How was what you did different from that …. and the test you were given which was pretty much just writing?*

S1: *You could definitely visualize with all the experiment stuff which was a lot easier, so you could write more about it, about what happened, instead of just writing about it.*

S2: *This doesn't feel like a test if you give us a piece of paper and say start now.*

S1*: All tense and everything.*

S3: *I think it helped us learn as well because like you had to think about it more rather than just writing it down. We went more into it and used it a bit better.*

Teacher views

Both Meg and Barry saw a range of positive effects in student engagement with multi-modal representations. Both teachers considered that asking students to design their own representation of what they had learnt about the topic was very motivating, but claimed students needed a template or finished product to guide their work. While the teachers thought that student exposure to a model product directly on the topic would only encourage mimicry rather than deeper learning, they claimed that students often need a framework or instructional model to guide their thinking. Barry considered that the lack of scaffolding and instructional support had undermined the effectiveness of the jigsaw activity of different representations of the same concept. On the other hand, with able students, he considered that the larger range of representational resources allowed strong students to produce outstanding work. In commenting on the work of the pair of student who produced the Powerpoint animation of a corkscrew opener's action he made the following observations:

> *It's the depth of learning that the kids are working at. It's not just engagement. That's what I reckon we really got out of this. With the good kids, particularly with those two boys who did the corkscrew, they are really bright kids, that's a pretty special bit of work. It demonstrates their understanding, and they've sat there and really enjoyed it. It's really quite deep understanding to put that together. They've had to talk quite deeply about it.*

Barry noted that these students were intently focused on making accurate observations for their representation, and were willing to tackle a multi-modal representational task beyond any task he had envisaged. He also considered they could demonstrate more knowledge through this format than through paper-based testing:

> *With the Powerpoint it led to that (the Powerpoint animation). I would never have thought of ever doing that. And they went with that. They can create the movement and show things. I found I wasn't limiting them to my limits, letting them go with what they could do.*

A key aspect of assessment for Barry was informal monitoring of student group discussion which he considered offered rich evidence of the level of students' conceptual understanding. He claimed that listening to students' discussion on how to represent their investigation strongly revealed both their practical and theoretical understanding of the topic.

Meg considered that students' work on constructing a multi-modal representation of an investigation was strongly motivating, and produced more effective learning than text-book reading, note-taking, or other strongly teacher-directed activity:

> *They will definitely have a better understanding of particles, because that was pretty much covered (in their Powerpoints), the part of the topic that deals with effect of heat on matter, and they will certainly have better knowledge, and I would suspect they would do better on their test. They would do better, because there was a focus on what the particles are actually doing.*

However, she also claimed that some students also required a model or a template to guide their work on their representation, and that she had to provide extensive support for some student groups. Reflecting on the broad effects of an explicit representational focus, Meg considered that it could enhance student learning:

> *If it became part of their learning, part of the way they did science, to come to expect that today we are going to try and demonstrate our understanding of a concept by use of a diagram, or next time by talking about it, then they would develop skills that would help, and the next topic there would be skills they could transfer to the new topic, assuming they are going to use a similar range of representations.*

Implications

These findings have various implications for developing students' understanding of the literacies of science. Teacher and student comments indicate that a major challenge entailed in student engagement with multi-modal representations is the question how much guidance and explicit teaching of representational conventions should be undertaken. The student work produced in each case study offers strong support for diSessa's (2004) contention that students are likely to have rich meta-representational competence in understanding aspects of the nature, purpose and preferable features of science texts, based on past experiences in science classes and previous experiences with many kinds of visual texts that aim to explain spatial and/or temporal relationships. This study suggests that the teacher needs to ascertain what students collectively and individually understand about these features, and then provide timely and relevant practice in representational tasks appropriate to the topic under investigation. For example, students need to have some knowledge about the purpose of graphs, their typical structural and functional features, and the operators that enable interpretation of graphs, before they are expected to represent their understanding of a topic in graphic form. As noted by diSessa (2004), there is some degree of developmental predictability in student acquisition of meta-representational competence, but teachers need to be responsive to the needs and knowledge of their students in framing representational challenges.

A further implication is the question of how much variation from convention or conceptual accuracy should teachers accept or tolerate in student-generated representations. Student products in both cases in this study, and illustrated in the two pieces of group work, indicated a tendency to experiment with the expressive possibilities of technological texts in ways that diverged from the typical conventions of science discourse. Students also might use a representational mode that is not suited to achieving precision or clarity in showing understanding, or they might construct a representation inaccurately. As evident in the responses of Meg and Barry to their students' work, there is a need for teacher to be keenly informed readers and viewers of their students' products and intentions. There is a need for a strong focus on the conceptual accuracy of student work, but also to guide the students towards standard practices. However, as Lemke (2004), diSessa (2004) and many others have noted, scientists are always designing new representations, especially as new technologies continue to change the conventions for how science is conducted and reported, particularly in net-based texts. As diSessa (2004) points out, the quality of a representation should always be judged by its purpose. While students are expected to learn that the science community highly values systematicity. brevity, completeness, and absence of ambiguity in scientific representations, students need to be given scope to learn through own experimental design work the aptness of these meta-representational values. This suggests that teachers need to exercise some degree of flexibility in the prescriptions they might offer students about appropriate conventions to draw upon as they interpret and construct science texts. It is probable that these teachers need to work with students developmentally along a continuum of skill competence with the conventions themselves.

The findings of this study complement current research on maximizing the effectiveness of designed representational environments by focusing on the need to take into account the diversity of learner background knowledge, expectations, preferences, and interpretive skills. The procedures that students use in constructing their own multi-modal representations, and the developmental pattern to these procedures (diSessa, 2004), provide insight into design features that could be explored in effective teaching representations for different age groups. There is a need for more classroom-based research on this interface between student- and researcher-designed representations, as undertaken by Russell and McGuigan (2001), and Dolin (2001).

Teacher and student perceptions of factors affecting learning in the two case studies reported in this paper are too diffused to offer any strong confirmation of Ainsworth's (1999) theory of how interpreting multi-modal representations enhances learning. As Ainsworth (2006) recently noted, the complexity of the cognitive tasks learners face in translating effectively across modes, and the effects of context, student knowledge and purposes on this translation work, are only starting to be appreciated fully in research in this field. However, the teacher and student responses suggest generally that designing multi-modal representations of science concepts enables learners to construct a deeper understanding. In the case of the Powerpoint on diffusion, the student's comments indicate that she understood the function of particles across different representations, implying an increasingly abstracted understanding of this conception of matter. However, further representational work with different applications would be required to confirm this point. Our study suggests that there is a need for more research that focuses in appropriate detail on students' perceptions and specific strategies in relation to this design and translation work across modes in particular science topics.

As noted at the outset of this paper, effective pedagogy in science must entail engaging students' interest and enhancing their perception of real-world applications in their learning. Our findings confirm there are potentially strong motivational gains in providing guided opportunities for students to design explanatory representations of their conceptual understandings, but this still leaves open the question of how these or other new representations might enable learners to connect what they have learnt with the world beyond the classroom.

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