Chapter 18
Representation Construction as a Core Science Disciplinary Literacy

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Abstract There is growing interest in and understanding of the material basis of epistemic practices in science, and consequently of the role of multimodal representation construction in reasoning and learning in science classrooms. From this perspective learning in science crucially involves induction into the interplay between experimental exploration and construction and coordination of representations as a core element of scientific disciplinary literacy. In this chapter we argue that learning to explain and problem-solve effectively in science involves students actively generating and coordinating multiple, multimodal representations and material artifacts in exploring material phenomena, in a guided inquiry process. We describe the development of a 'representation construction' approach to inquiry in science classrooms that is grounded in pragmatist perspectives on learning and knowing, which engages students in active experimental exploration and generation and refinement of core representations underpinning science concepts. We provide evidence of the success of the approach in supporting quality learning and reasoning. We propose that the construction of representations such as drawings, animations, role-plays or mathematical/symbolic systems works to support learning and knowing through the affordances of different modes to productively constrain exploration and explanation of the material world. We conclude that induction into multimodal representation construction processes in response to grappling with real world problems is central to the development of scientific disciplinary literacy, and that this approach represents a significant innovation in its use of authentic inquiry to serve a serious conceptual learning agenda in science.

Keywords Literacy · representation · affordances · concepts · inquiry

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18.1 Introduction

Increasingly science education researchers accept the sociocultural insight that learning in science, as with any discipline, entails students being inducted into the particular processes through which knowledge is generated, validated and communicated in this discipline. By implication, in learning science, students are acquiring a distinctive disciplinary literacy (Linder, Ostman, & Wickman, 2007; Moje, 2007; Norris & Phillips, 2003; Shanahan & Shanahan, 2008). Norris and Phillips (2003) argue that rather than being knowledgeable about science content, with a declarative focus, really understanding science needs to involve students becoming literate in the sense of being able to interpret, assess and represent scientific claims. This moves the focus from science as knowledge in the abstract to science as a discourse, as a set of practices for thinking, acting and representing claims scientifically. From this perspective, science disciplinary literacy entails both meaningful immersion in the epistemic processes of science inquiry and knowledge-generation (Duschl, 2008), as well as the ability to generate science texts to represent and communicate scientific claims arising from these processes. More broadly, this literacy also entails understanding and valuing the rationale for this disciplinary enterprise (Hurd, 1998). In this chapter we focus mainly on the role of representations in science learning processes, but also consider their relation to text interpretation and production.

There is increasing recognition of the role of material and representational tools in framing how the world is perceived and how theory is constructed (Amin, Jeppsson, & Haglund, 2015). Latour (1986, p. 3) argued that the emergence of scientific thought depended on the development of representational tools or ‘inscriptions’ that can be combined, transformed across modes including being turned into figures or supported by writing, and reproduced. His study of two scientists working together on soil profiles in the Amazon basin, at the boundary between rainforest and savannah, traced the process by which they generated data and progressively transformed it into the theory reported in scientific papers, representing abstracted and transportable knowledge, through a series of representational redescriptions. The raw soil was assembled into an ordered box arrangement, analysed and represented through a colour chart and numbering system, to a table which was the form in which they carried the information back with them to Paris to be further transformed into a scientific paper. The relation between the theoretical scientific claims made in papers, and raw data, is not unitary as imagined in much of the writing on the epistemic processes of science, but rather distributed across these representational redescription pathways. Drawing on these insights, we argue that the process of induction into scientific disciplinary literacies needs to include an appreciation, gained through practical problem solving, of the way data is generated and shaped, and progressively transformed through representation construction and redescription across modes.

A substantial body of work now exists that confirms the central role of representational generation and manipulation in the process of scientific discovery.

Gooding's research into Faraday's work on the relation between magnetism, electricity and motion, realised through his detailed diary accounts, demonstrated the central role of representational generation and refinement and improvisation in developing 'plausible explanations or realisations of the observed patterns' (Gooding, 2005, p. 15). Gooding identified a recurring pattern in Faraday's work, whereby he would generate chains of diagrams moving from 2D to 3D to 4D (involving representation of temporal change) and back to 2D as a general principle was established (Tytler, Prain, Hubber, & Waldrip, 2013).

This recognition of the key role of visual representation and reasoning is reflected in a strand of research in science education that investigates effective pedagogies to develop modeling competence aimed at the capacity for visualisation (Gilbert, 2005; Gilbert, Reiner, & Nakhleh, 2008, p. 3). Researchers working within a conceptual change tradition, such as Vosniadou (2008a, b), diSessa (2004), Duit and Treagust (2012), have incorporated representational work as a feature of pedagogies aimed at student conceptual growth. Researchers within a socio-semiotic tradition have investigated the challenges for this new literacy of harnessing the resources of a scientific multimodal discourse (linguistic, mathematical and visual) to identify the challenges of learning this new literacy (Gee, 2004; Kress & van Leeuwen, 2006; Lemke, 2003). Our own research sits within a sociocultural tradition that has focused on the meaning-making practices of scientists to provide the major lead for developing classroom pedagogies that align with these (Greeno & Hall, 1997; Hubber, Tytler, & Haslam, 2010; Lehrer & Schauble, 2006a, b; Manz, 2012; Tytler & Prain, 2010). Each orientation foregrounds representational competence as crucial to learning science.

Socio-semiotic research represents a diverse range of approaches to formal analyses of meaning-making processes and practices in science discourse and activity. They include genrist approaches (Halliday & Martin, 1993; Parkinson & Adendorff, 2004) focusing on textual features that affect interpretation, taxonomic structuralist accounts of visual language (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001), post-structural multimedia semiotics and discourse analysis (Lemke, 2004), and sociocultural perspectives on science discourse (Gee, 2004; Moje, 2007) that seek to foreground the effects of situational factors on different learner cohorts' engagement with science. These perspectives are broadly united by the view that students must learn primarily to understand and reproduce the meaning-making practices of the science community if they are to become scientifically literate (Bazerman, 2009; Klein & Boscolo, 2016; Unsworth, 2001). Prescribed genres to achieve this end include formal laboratory reports, posters and science workbooks. However, the issue of which writing types will best facilitate disciplinary learning remains an open question.

In our own approach to the development of scientific disciplinary literacy, we take as a starting point that classroom work should involve induction into scientific disciplinary norms through enacting pedagogical processes parallel to those of practicing scientists. We draw on the work of Vygotsky (1978, 1981), and researchers such as Keys, Hand, Prain and Collins (1999), Moje (2007), Lehrer and Schauble (2006a, b), Duschl (2008) for this focus. While we recognise that classroom teaching and learning practices differ from those of practising scientists in purposes, knowledge bases, resources and rewards, we argue that they can parallel in productive ways the processes of inquiry of the research laboratory through engaging with experimental exploration and representational generation, refinement and validation. The classroom community can be configured to parallel the research team community, where students use practical workbooks to engage in experimental design, observations, reflections, and representing scientific reasoning and claim-making. This approach not only focuses on developing applied representational competence, but also includes formal genres such as posters and reports.

In developing scientific literacy, students need to learn to switch between material, verbal, written, visual, mathematical and 3D modeling modes, including digital form, and coordinate these in generating and justifying scientific explanations. They need to participate in authentic knowledge-producing activities that require the use of these culturally specific resources to develop competence in the diverse reasoning practices of science (Ford & Forman, 2006). In this, the classroom operates as a learning community in which their representations are shared, discussed and justified to arrive at a reasoned consensus that is consistent with accepted scientific understandings (Greeno, 2009; Kozma & Russell, 2005).

In our own approach to engaging students in disciplinary literacy practices, we acknowledge that teachers and students need to know the form and function of both generic and discipline-specific representational conventions. We argue that students, in learning to use these, are advantaged by having first-hand experience of the affordances of the different representational modes as they generate and use them to solve problems and construct explanations. Representations and their use perform active conceptual work in shaping how phenomena are perceived and understood, and this is true for learning in classrooms (Kozma & Russell, 2005) as it is for science (Gooding, 2006). They are the reasoning resources through which we know, and cannot be seen as simply tools for understanding some higher, abstracted form of knowledge that evades representation. We have argued that concepts must be understood through the representational practices through which they are performed (Tytler, Haslam, Prain, & Hubber, 2009). From our perspective, student learning proceeds through the active engagement with and coordination of representational resources, with different representations and modes having specific affordances that offer insight into a phenomenon through productively constraining attention (Prain & Tytler, 2012). Thus, for instance, as students construct drawings of invertebrates in response to a challenge to explain their movement, they select key features needing representation, notice and make claims about relations between structures, and abstract as they refine and coordinate the spatial and temporal features of the animals' structures relating to movement. Such drawings represent a claim, and can involve substantive reasoning. Similarly, role plays can focus attention on key spatial and temporal features of phenomena, and again productively constrain attention to provide embodied engagement with, in this same example, the animal's movement mechanisms. It is our contention that actively engaging with the construction of material and symbolic representations offers gains through this process of productive constraint, and that understanding of a phenomenon entails the coordination of multiple representations each offering partial explanatory insight.

18.2 Describing the Representation Construction Inquiry Approach

Over 3 years of an Australian Research Council-funded project – The Role of Representation in Learning Science (RiLS) – we worked with a small number of teachers of science, both primary and secondary, to develop and refine an approach to guided inquiry teaching. The project used a design experiment methodology (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) where an iterative process of development and trialing, and evaluating outcomes was conducted with teachers as partners in the process. The team suggested activities and activity sequences that involved challenging and supporting students to generate representational responses to explicit material problems and challenges, which were then refined and embellished, and further developed by the teachers. This process involved regular planning meetings with the teachers, analysis of video records of teaching sequences including records of student groups' discussion and artefacts, feeding back into further discussion. The research team brought to the planning process a detailed knowledge of the literature around student conceptions and learning challenges in significant topics such as force and motion, adaptation, or changes to substance, and ongoing analyses of the key representational resources that underpinned these major conceptual topics. The teachers brought knowledge of their students' capacities and experience of the practicalities of establishing productive classroom investigations and processes. As the teachers become more confident and self-generating in the approach, they took increasing control of the process of planning and implementation. Investigation of the development of the teaching approach, and teachers' experience, was based on video capture and analysis, and teacher interviews (Hubber, Tytler, & Haslam, 2010). Documentation and analysis of student learning occurred through analysis of class discussion through whole class and small group video capture, collection of student artefacts, pre- and post-tests, and student stimulated recall interviews (Tytler, Prain, Hubber, & Waldrip, 2013), where ethical considerations, such as voluntary participation, informed consent, and use of pseudonyms were followed.

In a series of research workshops involving both the research team, critical friends and the partner teachers, the major principles of the approach were identified, and progressively refined. That process has been continued over subsequent projects, described below, so that the major features of the approach are:

1. Students construct representations in response to explicit challenges. This process involves strategic scaffolding so that students' representational work is focused and productive. The challenge involves a shared practical problem that is meaningful to students.
2. The representation work is underpinned by experimental exploration or appeal to evidence based in experience.
3. Teachers orchestrate shared discussion/evaluation of representation work.
4. There is explicit discussion of representations and representational adequacy and their role in science knowledge building.
5. Assessment is ongoing and a core aspect of learning.

18.3 The Nature of Representational Work in the Inquiry Approach

The nature of a representation challenge is diverse, and how a challenge is orchestrated is a core skill in the teaching and learning process. In some cases a challenge or series of challenges might begin a topic, for instance in introducing the arrow convention of force through a series of tasks in which students struggle to communicate the action of force on a piece of plasticine (Hubber, Tytler, & Haslam, 2010), in representing the imagined relations between particles in a solid to explain specific properties such as elasticity of rubber, or expansion of metal on heating (Hubber & Tytler, 2013), or in planning and constructing a 3D model of an invertebrate to explain its movement (Tytler, Haslam, Prain, & Hubber, 2009). In other cases teachers might plan a sequence of challenges involving representational redescription across modes, such as a sequence of activities in which students develop their understandings of particle models of evaporation using role-play, drawing, discussion of a 3D demonstration, and a cartoon representation of a single particle's history (Prain & Tytler, 2012). In cases where the scientific model is more complex, students may begin by redescribing an existing model in response to a specific challenge, such as taking digital simulations of the rotation of the earth and constructing drawings to explain how the sun moves around the horizon when seen from above the arctic circle in the northern summer (Hubber, 2010).

The following examples of students' representational work to illustrate the approach occurred within junior secondary classrooms from an Australian metropolitan school. The teachers were teaching the nationally set curriculum which mandated that students learn 'sedimentary, igneous and metamorphic rocks contain minerals and are formed by processes that occur within Earth over a variety of timescales' (ACARA, 2012). The initial exploration of rock types occurred by students in small groups creating a dichotomous key from a chosen boxed set of several rocks from a collection of sets. The evaluations of the keys were undertaken at the small group level whereby each group was to self-assess their own key in addition to evaluating another group's key by testing it with an unknown rock. Students as part of the sequence also explored the modeling of the earth's internal structure, critiquing models based on a boiled egg, and an orange, in terms of features that were and were not represented. Central literacy features of these activities were student representational construction of multimodal text, critique of models and understanding of the purpose of models.

A main learning outcome of the teaching sequence was for students to gain an understanding of the rock cycle whereby students get insights into the nature of the main rock types in addition to the processes by which they are individually formed and the processes by which one rock type can transform into another. There was not one canonical rock cycle that was advanced by the teachers for the students to study. Rather, students were to critique different diagrammatic forms of the rock cycle to then construct their own rock cycle. In the

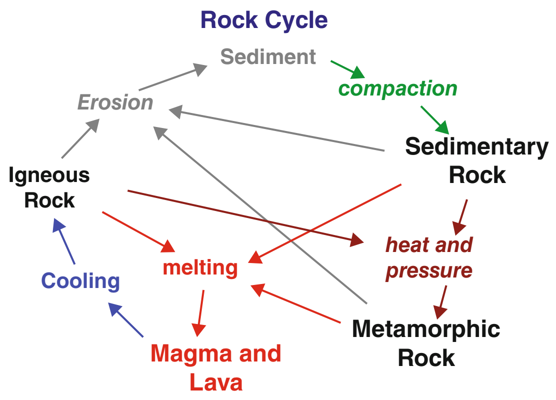


Fig. 18.1 Small group critique of diagrammatic forms of the rock cycle

following example, the teacher laid out seven different diagrammatic forms of the rock cycle in different locations in the classroom. In groups of three students they were to move around the room critiquing each rock cycle in terms of addressing the questions, 'What does it show well?' and, 'What does it not show well?'. Figure 18.1 shows a particular rock cycle with a transcript of a discussion between the group and their teacher following the group's critique of the rock cycle representation.

T: *Looking at the cycle what can you tell me about it?*

S1: *It shows how everything is formed and connected*

T: *When you say everything what do you mean?*

S1: *The types of rocks*

S2: *And it is colour coded too*

T: *Does that help?*

S2: *Yes because if you follow the arrows you find what you are looking for.*

S1: *For example, both sedimentary and igneous rocks have similar processes that they can through heat and pressure form the metamorphic rocks* [pointing to the dark red arrows] *… it shows how they are connected to the metamorphic rock*

S3: *… it gives you options about where to go*

S1: *The second example is sedimentary rocks can melt to form magma, which when it cools becomes igneous rocks; the igneous though can become a sedimentary rock once again through erosion [tracing the path with an pen]*

T: *So erosion is leading from that one* [pointing at igneous]

S1: *Connected to sediments to sedimentary …*

S2: *its like a never ending cycle* [point out various cycle on the diagram]

T: *Does it show weathering?*

S1: *it shows erosion but doesn't show weathering*

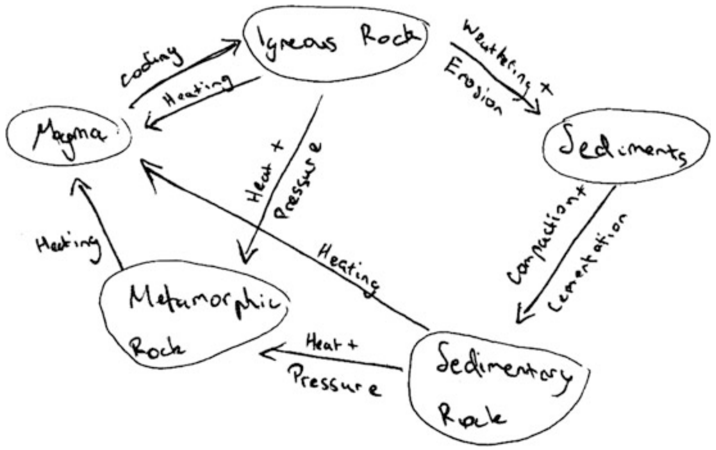


Fig. 18.2 Student constructed rock cycle from an end of sequence test

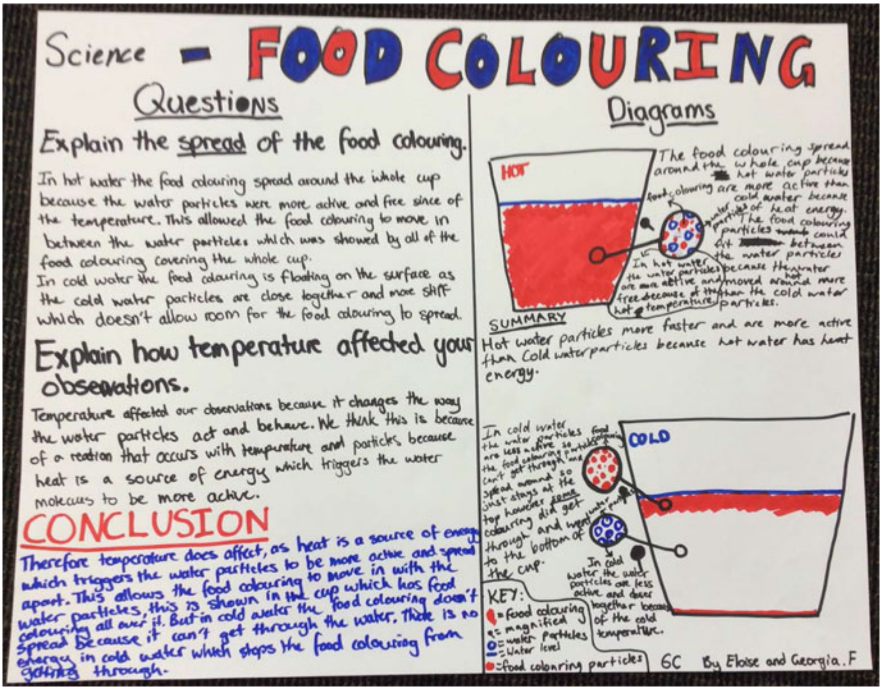
T: *So does this help explain the ideas?*

S2: *Looking at it first it was kind of confusing but once you had time to look at it and follow the arrows it makes a lot of sense.*

From the discussion students were challenged to construct their own rock cycle. None of the students chose a rock cycle from the critique challenge in its entirety but chose to take various features from several rock cycles to construct their own. Tests at the end of the sequence then a subsequent formal exam showed a consistency and high quality in students' representations over time. Figure 18.2 shows one example of a rock cycle constructed during the end of sequence test, illustrating engagement with diagrammatic claim-making and with the rock cycle concept.

As part of the approach, students engage with complex forms of reporting, including posters of extended investigations, group constructed models with explanatory digital text, or reports of investigations. Figure 18.3 shows a Grade 5/6 students' report of a group investigation into the dissolving of food colouring in hot and cold water, with explanatory text supported by diagrammatic particle representations. The class had discussed particle ideas and the group explorations were accompanied by a class brainstorm of ideas about dissolving, with the report instructions emphasising explanation and visual representation. The coordination of diagrams and text had been modeled consistently on the whiteboard and in reporting on teacher-scaffolded investigations.

This work is in some respects similar to a formal template of the type traditionally used for practical reports, except that the emphasis is on explanation rather than stepping out prediction, method etc. The students here have clearly engaged with the problem and the text and drawings represent complex claims related to experimental evidence. We argue, acknowledging Lemke's (2002) point that the science community does not follow the genre norms often promoted



Science - FOOD COLOURING

Questions

Explain the spread of the food colouring.

In hot water the food colouring spread around the whole cup because the water particles were more active and free since of the temperature. This allowed the food colouring to move in between the water particles which was showed by all of the food colouring covering the whole cup.
In cold water the food colouring is floating on the surface as the cold water particles are close together and more stiff which doesn't allow room for the food colouring to spread.

Explain how temperature affected your observations.

Temperature affected our observations because it changes the way the water particles act and behave. We think this is because of a reaction that occurs with temperature and particles because heat is a source of energy which triggers the water molecules to be more active.

CONCLUSION

Therefore temperature does affect, as heat is a source of energy which triggers the water particles to be more active and spread apart. This allows the food colouring to move in with the water particles, this is shown in the cup which has food colouring all over it. But in cold water the food colouring doesn't spread because it can't get through the water. There is no energy in cold water which stops the food colouring from getting through.

Diagrams

The food colouring spread around the whole cup because [illegible] hot water particles are more active than cold water because of heat energy. The food colouring particles ~~want~~ could fit [illegible] between the water particles because the hot water moved around more than the cold water particles.

In hot water the water particles are more active and free because of the hot temperature.

SUMMARY
Hot water particles more faster and are more active than Cold water particles because hot water has heat energy.

In cold water the water particles are less active so the food colouring particles can't get through and spread around so just stays at the top however some colouring did get through and went to the bottom of the cup.

In cold water the water particles are less active and closer together because of the cold temperature.

KEY:
= food colouring
= magnified
= water particles
= Water level
= food colouring particles

6C By Eloise and Georgia.F

Fig. 18.3 Student report on a dissolving investigation, focused on explanatory text

as central to scientific disciplinary literacy, that such productions are important and generative examples of engagement with scientific literacy practices, using representational resources including text as tools to engage with significant reasoning. The tools achieve potency and meaning through their bending to interpretive, explanatory purposes that are both fresh, and shared within the classroom community.

Schools we have been working with on this inquiry approach have increasingly seen the value of text production within student workbooks that are lined on one side and blank on the other, encouraging diagrammatic exploration and presentation of ideas. Figure 18.4 shows an excerpt from a workbook in which a student, following class discussion on gravity, the moon and tides, plays with different ways of representing gravity on different objects. A subsequent entry represents how tides form and also explains why the moon doesn't fall to earth. Teachers have reported how students take great pride in these workbooks as evidence of their developing ideas. The workbooks sit within a strong tradition in science of field note taking and journal writing, both genres that play to informal and formal reasoning in developing science knowledge, and that capture important aspects of the interplay of evidence and idea generation in the representation circulation processes leading from data to knowledge production (Latour, 1999).

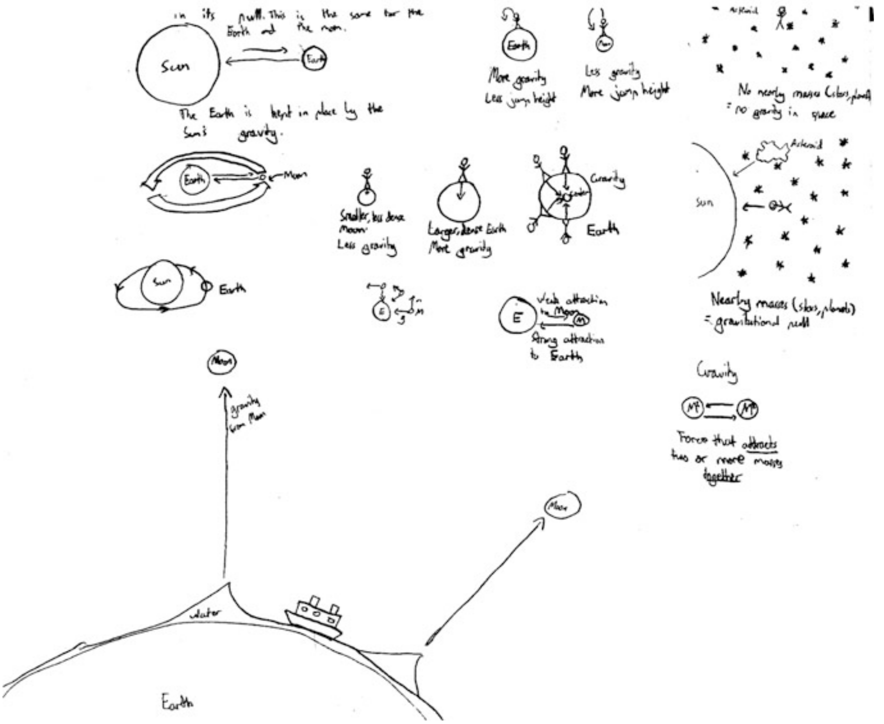


Fig. 18.4 Student workbook entry in response to a challenge to represent how gravity affects astronomical objects, and tides

18.4 Student Learning Outcomes: Building Disciplinary Literacy

In arguing for the authenticity and effectiveness of the approach for building students' disciplinary literacy, we argue that scientific disciplinary literacy involves a number of facets that are attended to by the approach:

1. Genuine engagement with classroom practices that parallel the epistemic practices of science;
2. Representational work that indicates commitment to explanation and problem solving through creating non-standard representational resources;
3. Evidence of high level reasoning through engagement with representational practices;
4. Mastery of science conceptual understanding of key concepts;
5. Productive disposition demonstrated by motivation to pursue investigation and problem solving;
6. Meta representational competence demonstrated by understanding of the role of representations and models in knowledge production and dissemination;

7. Flexible adaptation of traditional science genres to engage and extend student learning;
8. Explicit discussion of representational form and function and modeling of the integration of different modes.

To evaluate the effectiveness of the approach in building disciplinary literacy we draw on a number of sources of evidence to deal with these aspects of literacy in turn. First, in our original research developing the approach, video evidence of classroom activities and discussions shows students involved with high level problem solving as they develop individual representational practices to investigate and communicate populations of invertebrates in the school ground (Tytler, Haslam, Prain, & Hubber, 2009), build representations of animal movement, or develop and critique representations of force in explaining motion (Hubber, Tytler, & Haslam, 2010). Students work in groups and whole class discussions to construct and refine representations, drawing on empirical observation and experimentation in ways that parallel the operation of research laboratories (Tytler, Haslam, Prain, & Hubber, 2009). There is evidence also of increased student engagement with ideas and motivation, across the spectrum from advanced classes being challenged with high level problem solving, to lower level classes where teachers report students becoming more engaged with the active participation implied by the approach in contrast to more teacher delivered material.

Second, the level of student representational work in solving challenges is evidenced by the examples above. Similarly, examples from a range of topics and year levels show imaginative and individual engagement with representational work in solving problems, such as particle representations of evaporation from wet handprints or puddles demonstrating representational flexibility and conceptual ideas beyond expected for the grade level (Ainsworth, Prain, & Tytler, 2011; Tytler, Prain, Hubber, & Haslam, 2013), or engaging with astronomical problems using multiple and multimodal, sophisticated representations (Hubber, 2010) that show detailed command of astronomical perspective through diagrammatic work.

Third, with regard to high level reasoning through representational work, teachers have consistently attested to the liveliness and depth of classroom discussions around representational practices, more so than with traditional pedagogies. Again, evidence from video and student artefacts show significant reasoning occurring at multiple points in the representational work, from data generation structured by representational framing, to interpretation of observations and data and argumentation around representation construction, to analysis and argumentation around representation evaluation (Tytler, Prain, Hubber, & Haslam, 2013).

Fourth, while there has been no formal comparative research carried out, comparing the approach with other approaches, pre- and post-test data has consistently shown a significant gain in understanding as measured on multiple choice items. We have used, for instance, a recognised astronomy test instrument as part of an astronomy sequence in the RiLS project, to track outcomes. The test was used by Kalkan and Kiroglu (2007) in a study that involved 100 pre-service primary and secondary education teachers who participated in a semester length course in astronomy. This allows us to compare results with those obtained by Kalkan and Kioglu, who used the normalised gain index, <*g*>, as a measure of comparison of pre- and post-test results (Zeilik, Schau, & Mattern, 1998). <*g*> is a measure of the ratio of the actual average student gain to the maximum possible average gain: <*g*> = (post% − pre%)/(100 − pre%). Gain index values can thus range from 0 (no gain achieved) to 1 (all possible gain achieved). For multiple choice questions, a gain index of 0.4 for an item indicates that for instance if 50% of students in the pre-test answered the question correctly, 70% answer correctly in the post test, being 0.4 of the possible gain from 50% to 100%. Kalkan and Kiroglu (2007, p. 17) reported a mean gain of a 'respectable 0.3'.

In our original study we worked, at secondary level, mainly with two teachers, Lyn and Sally, who were biology majors. For our second sequence, a four-week year 8 astronomy unit they expressed lack of confidence in astronomy concepts. A third teacher, Ben, who was a physics major and confident with astronomy, initially joined the project but shortly after the planning sessions he declined to continue on the grounds he preferred to teach astronomy as he had previously done. During the unit, Lyn and Sally progressively increased in confidence. The pre- and post-test data was collected for all three classes, which were not streamed, and the results for the gain index are shown in Table 18.1 for Lyn and Sally, and Ben, compared with the Kalkan and Kioglu results. The gain index shows clearly that the two classes using a representation construction inquiry approach outperformed by a wide margin both the class taught by the physics specialist, Ben, and the pre-service teachers undertaking a semester length course. Comparison using a two-tailed *t*-test showed difference at significant levels of 0.013 against Ben, and

Table 18.1 Normalised gain indices for Sally and Lyn's classes compared to Ben, those reported by Kalkan and Kioglu, and a later set from Sutton school using the approach

	Astronomy Context	Sally & Lyn	Ben	K&K	Sutton
1	Day and night	0.785	0.83	0.22	0.8
2	Phases of the moon	0.605	0.38	0.09	0.36
3	Sun Earth distance scale	0.4	0.13	0.05	0.44
4	Altitude of midday Sun	0.635	−.31	0.14	0.53
5	Earth's diameter estimate	0.415	0.23	0.09	0.44
6	Seasons	0.59	0.13	0.61	0.23
7	Sequence of objects from Sun	0.5	0.38	0.46	0.49
8	Time for Moon's orbit of Earth	0.75	0.71	0.22	0.72
9	Time for Earth's orbit of Sun	0.875	−1	0.41	0.7
10	Eclipse and phase of moon	0.795	0.42	0.22	0.32
11	Moon's motion around Earth	0.5	0.23	0.17	0.48
12	Centre of universe location	0.5	0.33	0.66	0.48
13	Seasons	0.9	0.5	0.64	0.81
	Mean gain index	0.63	0.23	0.31	0.52

0.00033 against the K&K result. This gain has been repeated for a number of classes since this initial investigation, for astronomy (results for Sutton school, Year 7, are shown as the final column) and also for other challenging topics such as the particle nature of matter (Tytler, Prain, Hubber, & Waldrip, 2013, p. 47). This comparison should be taken as indicative rather than a formal experimental proof, since there are unaccounted-for, possibly confounding factors present in the comparisons, and we do not know in detail what Ben's approach entailed. Nevertheless, the consistent strength of the gain across classes and topics does indicate a strong conceptual outcome attributable to this inquiry approach, on measures that target acknowledged high level concepts in difficult topics.

Fifth, students interviewed concerning their response to the approach, and teacher perceptions of student engagement with learning, show consistently increased motivation to become involved in pursuing representational practices and high level ideas, through group work and in classroom discussion. Teachers have reported being surprised by high levels of student competence and commitment to problem solving.

Sixth, a key feature of the approach is explicit discussion of the nature and role of representations in learning and reasoning about phenomena. Test items have been constructed that explore students' understanding of the nature of models in scientific explanation (Tytler et al., 2013, p. 45). Teachers report that students who have been exposed to the approach for a year or more become sophisticated consumers of text book representations, offering critique as a matter of course. As Lyn described (Tytler et al., 2013, p. 48):

> … we're not teaching the particle model as in, this is the model and see how it relates to real life. It's more, this is real life and we have a model and does it actually explain real life, and does it explain this and that? And particularly … how good is the representation?

A year 8 student, in interview, described the relationship between representations thus:

> Through many representations you can come to an understanding. So many representations help you get an understanding … but then, through your understanding you can give many representations. So it works both ways. (Tytler et al., 2013, p. 48)

Thus, we argue that through this guided inquiry approach students can achieve a meta-level competence in the disciplinary literacies of science, through explicit attention to the nature of representations and their role in reasoning, learning and knowledge building.

Seventh, and finally, student production with the method is varied and primarily associated with the construction of multimodal text to generate and justify ideas. Traditional disciplinary genres are positioned in this production as resources to support reasoning, advancing claims and supporting these with evidence. These practices are positioned within a classroom community of inquiry with a focus on the construction, critique and refinement of representational forms. We argue that in this way, the scientific literacies being developed engage students in meaningful epistemic processes and text production that are an important adjunct to the more formal literacy genres foregrounded in much of the disciplinary literacy literature.

We also acknowledge that our guided inquiry approach required refinements over time and also posed some significant challenges for participant teachers. These refinements included the need to develop a range of challenges, tasks and learning processes that (a) catered for mixed ability classes, (b) offered generative scope for diverse students' responses and (c) could be broadly aligned with prescribed learning outcomes in the national curriculum. The challenges for teachers included the development of skills in interpreting, guiding and consolidating progress as the students responded to sequences of tasks, made divergent claims, and raised unscripted challenges to the teachers' own conceptual and representational understandings. The teachers also had to manage time spent on this deeper learning against the content demands of the curriculum. However, as noted in the preceding paragraphs, there were many overriding learning gains, as noted by both teachers and students.

18.5 Conclusion

In this chapter we have argued that a view that learning science involves induction into scientific disciplinary literacies implies a need for the promotion of classroom practices that more authentically parallel the epistemic practices of the discipline. Contemporary perspectives on processes of scientific discovery foreground the crucial role of representations and representational work in framing, building and sharing new knowledge, and this therefore needs to be a driving consideration in framing classroom inquiry approaches.

We have further argued that our view of learning and knowing offers a powerful perspective on the importance of active inquiry in which students engage with experimental exploration and the creation and critique of representations in the pursuit of knowledge. This is supported by our account of representational affordance as productive constraint, as a way of understanding the way representation construction within guided inquiry can productively mirror science epistemic processes.

Our account of student work engendered by the approach emphasises both the nature of student experimental exploration and generation, evaluation and refinement of representations as they grapple with conceptual challenges, and the quality of the representational work that can ensue. We argue that the approach reveals important aspects of what it means to develop scientific disciplinary literacies, such as engagement in classroom processes that mirror scientific epistemic processes, reasoning through construction and coordination of representations that results in deepening conceptual knowledge, a disposition and capacity to engage with scientific problems, and the development of meta-representational competence and awareness. The approach shows promise of supporting students to develop these scientific literacies to a high level, as evidenced by the quality of student engagement with reasoning illustrated in our examples, and elsewhere in our writing (Tytler, Prain, Hubber, & Waldrip, 2013), and evidence from pre- and post-test results and teacher accounts.

While we acknowledge the importance of a focus on formal scientific genres in supporting literacy development, we argue that if we are to engage students in thinking and working scientifically, these need to be positioned as resources for reasoning within contexts in which students explore, make claims and reason about material phenomena through imaginative, multimodal text production that draws on diverse, often informal scientific practices and genres.

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