Enacting a representation construction approach to teaching and learning astronomy

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Introduction

There is increasing attention being given to the role of representations in learning science as part of growing recognition of the representational basis of knowledge creation in science and generally (Latour, 1999). Quality learning must involve richer and more sustained reasoning and engagement with the mediating tools of the discipline in ways that entail the acquisition of a subject-specific set of purpose-designed literacies (Lemke, 2004; Moje, 2007). There is an increased focus on students learning how to reason through visual, linguistic and mathematical modes. Much of recent research has placed emphasis on students learning to use scientific representations flexibly to visualize phenomena and problem solve. Students use the multi-modal representational tools of science to generate, coordinate and critique evidence (Ford & Forman, 2006), involving models and model-based reasoning (Lehrer & Schauble, 2006).

This study relates to a guided inquiry approach to teaching and learning, called representation construction, involving students constructing and negotiating multiple representations through sequences of representational challenges. Guided inquiry is defined as an intermediate teaching approach fitting between open-ended, student-directed learning and traditional, direct instruction (Furtak, 2006). The research is part of a wider program, an Australian Research

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Council (ARC) funded project titled Creating Representations in Science Pedagogy (CRISP, 2012-2015), which investigates the professional learning of teachers developing a representation construction approach. The study involves the planning and implementation of a unit on astronomy by a community of four secondary school teachers. This research aimed to document the experience of the teachers in implementing a representation construction approach, and to investigate the quality of student learning associated with different aspects of the pedagogy.

Development of the representation construction approach

A recent ARC funded project (2007-2010), Representations in Learning Science (RiLS), developed a theoretically sophisticated but practical, representation construction approach to teaching and learning that links student learning and engagement with the epistemic (knowledge production) practices of science (Tytler, Hubber, Prain & Waldrip, 2013a). This approach involves challenging students to generate and negotiate the representations (text, graphs, models, diagrams) that constitute the discursive practices of science, rather than focusing on the text-based, definitional versions of concepts. The representation construction approach is based on sequences of representational challenges, which involve students constructing representations to actively explore and make claims about phenomena. It thus represents a more active view of knowledge than traditional structural approaches and encourages visual as well as the traditional text-based literacies.

In developing this particular approach to guided inquiry teaching in science and in interpreting the nature of learning that flows from it, our perspective follows pragmatist accounts of the situated and contextual nature of problem-solving and knowledge generation (Peirce, 1931-58; Wittgenstein, 1972). We understand a pragmatist orientation as an empirical and systematic method of inquiry that involves a collective analysis of experience to establish reasoned knowledge, avoiding a priori judgments. In this account representations actively mediate and shape knowing and reasoning such that classroom teaching and learning processes need to focus on the representational resources used to instantiate scientific concepts and practices. In traditional accounts, representations are often cast as efficient and effective ways to introduce and illustrate abstracted concepts that are conceived of as distinguishable from the representations through which they are generated and communicated. From our perspective however, representations are the reasoning tools *through which* we imagine, visualise spatial relations and model astronomical phenomena. This view is also fundamentally Vygotskian, characterising representations as the disciplinary language tools that mediate thinking and knowing (Moje, 2007).

Accounts of scientific knowledge producing practices emphasise the fundamental importance of visuo-spatial representations in the imaginative practice of discovery (Gooding, 2004), and the way that data is transformed into knowledge through a series of representational "passes" (Latour, 1998; Nersessian, 2008). In this way we argue that the epistemological processes central to this representation construction inquiry approach mirrors the epistemic practices of science itself (Prain & Tytler, 2012).

RiLS has successfully demonstrated enhanced outcomes for students, in terms of sustained engagement with ideas, and quality learning, and for teachers' enhanced pedagogical knowledge and understanding of how knowledge in science is developed and communicated (Hubber, 2013, 2010; Hubber, Tytler, & Haslam, 2010). This representation construction approach shows promise of resolving the tension between inquiry approaches to learning science and the need to introduce students to the conceptual canons of science (Klein & Kirkpatrick, 2010).

The set of principles (Tytler et al., 2013b, p. 34) developed by the RiLS project that underpin the representation construction approach to teaching and learning are described as:

1. ***Teaching sequences are based on sequences of representational challenges:*** Students construct representations to actively explore and make claims about phenomena.

    a. ***Clarifying the representational resources underpinning key concepts*:** Teachers need to clearly identify big ideas, key concepts and their representations, at the planning stage of a topic in order to guide refinement of representational work.

    b. ***Establishing a representational need:*** The sequence needs to involve explorations in which students identify the problematic nature of phenomena and the need for explanatory representation, before the introduction of the scientifically accepted forms.

    c. ***Coordinating / aligning student generated and canonical representations:*** There needs to be interplay between teacher-introduced and student-constructed representations where students are challenged and supported to refine and extend and coordinate their understandings.

2. ***Representations are explicitly discussed:*** The teacher plays multiple roles, scaffolding the discussion to critique and support student representation construction in a shared classroom process. Students build their meta-representational competency (diSessa, 2004) through these discussions.

    a. ***The selective purpose of any representation:*** Students need to understand that a number of representations are needed for working with multiple aspects of a concept.

    b. ***Group agreement on generative representations*:** There needs to be a guided process whereby students critique representations to aim at a resolution.

    c. ***Form and function:*** There needs to be an explicit focus on representational function and form, with timely clarification of parts and their purposes.

   d. ***The adequacy of representations:*** There needs to be ongoing assessment (by teachers and students) of student representations as well as those representations introduced by the teacher.

3. ***Meaningful learning***: Providing strong perceptual/experiential contexts and attending to student engagement and interests through choice of task and encouraging student agency.
   a. ***Perceptual context:*** Activity sequences need to have a strong perceptual context (i.e. hands on, experiential) and allow constant two-way mapping between objects and representations.
   b. ***Engagement / agency:*** Activity sequences need to focus on engaging students in learning that is personally meaningful and challenging, through affording agency and attending to students' interests, values and aesthetic preferences, and personal histories.
4. ***Assessment through representations:*** Formative and summative assessment needs to allow opportunities for students to generate and interpret representations. Students and teachers are involved in a continuous, embedded process of assessing the adequacy of representations, and their coordination, in explanatory accounts.

These principles formed the basis of the current Constructing Representations in Science Pedagogy (CRISP) project (2012-2015) which aims at wider scale implementation of the representation construction approach. In introducing the approach to new teachers the CRISP researchers aim to identify key enablers, and blockers, that facilitate quality teacher learning and adaptation of the representation construction approach. This chapter documents the experiences of four Year 8 teachers from a Melbourne metropolitan private school who were initially introduced to the representational construction approach and then implemented the approach in a four-week teaching sequence in the topic of astronomy.

Research on students' understanding of astronomy

The significant amount of research into individuals' understanding of astronomy in recent decades has found that conceptions of the Earth and day-night cycle are relatively well understood by secondary school students, while the Moon phases, the seasons and gravity are phenomena that students, and adults, find difficult to understand and explain (Danaia & McKinnon, 2008; Kalkan & Kiroglu, 2007; Lelliot & Rollnick, 2009; Trumper, 2001). Common alternative conceptions found among students include: the phases of the moon are caused by the shadow cast on the Moon due to the Earth obstructing the light from the Sun; the seasons are caused by variations in distance between the observer on Earth and the Sun; and, gravity does not operate in the absence of air.

The prevalence of alternative conceptions for individuals across most age levels may suggest that school science has limited impact in resolving them. Bakas & Mikropoulas (2003) point out that the sometimes limited success of conventional teaching methods in overcoming students' alternative conceptions may be due to a lack of appropriate teaching aids in the form of representations that can intervene dynamically in the learning process and modify it.

Astronomical phenomena such as the seasons and phases of the moon are difficult for students to understand as they involve an understanding of three dimensional spatial relationships and orientations between celestial objects (Hegarty & Waller 2004; Padalker & Ramadas, 2008; Yu, 2005). Constructing explanations for astronomical phenomena requires learners to understand motion across frames of reference, coordinating Earth-based perspectives and space-based perspectives. A full explanation requires an ability to shift between these perspectives to explain the patterns in observations made from a rotating Earth and the actual motions and orientations of the objects in space (Plummer, 2014).

The teaching of astronomy needs to develop students' spatial visualization (the ability to imagine spatial forms and movement, including translation and rotations) and spatial orientation (perspective taking) (Padalker & Ramadas 2008; Hegarty & Waller 2004). These skills may be enhanced through carefully planned activities which use physical models and modelling as a key part of the pedagogy (Lelliot & Rollnick, 2010). Plummer (2014) suggests that students' spatial thinking can be improved through activities whereby students create spatial representations (maps, graphs, 3D models, gestures, etc.).

In this study we worked with the Year 8 teachers to plan and research an astronomy unit that used our guided inquiry approach in which students constructed and explored representations of the sun-earth-moon system. This approach is consistent with recommendations from the literature, described above, and in our planning with teachers we explicitly sought to address these learning difficulties associated with coordinating earth and space perspectives, described above. Our aim was to investigate the teachers' experience of developing and refining the approach, the quality of learning arising from the approach, and teachers' perceptions of the key aspects of the pedagogy that led to deeper learning. Our research questions were:

1. What are teachers' perceptions of the effectiveness of the representation construction approach in supporting student learning of astronomy?
2. What aspects of the approach do teachers perceive as key to its support of student learning?
3. What evidence is there that the approach leads to quality learning of astronomy?

Methodology

The research reported in this chapter sits within the wider CRISP study which aims to develop and refine a professional learning approach that is effective in establishing a guided inquiry approach to teaching and learning science based on representation construction. The methodology is one of Design Based Research (Collins, Joseph & Bielaczyc, 2004) in which the intent is to systematically develop and refine ways of working with teachers to effect changes in their epistemological and pedagogical beliefs and practices. Design based research has a dual focus on theory development, and development of contextually appropriate processes. Design experiments are typically 'test beds' for innovation and the theory they develop must do real work, in the pragmatic tradition (Cobb et al., 2003). Design experiments are characterised by a cyclical process of refinement and evaluation with the data generated being often messy and multi layered, being grounded in complex teaching contexts, often involving a mix of qualitative and quantitative data. Within CRISP the research is conceptualised as a partnership between teachers and researchers, with teachers participating in workshop discussions concerning the efficacy of the approach and ways of refining it to further improve student learning. Teachers have on a number of occasions co-presented with the research team at conferences.

For the particular 'design experiment' described here, the focus is not on the change process but on investigation of teachers' perceptions of the pedagogy and its effectiveness, as part of the design cycle. The methodology is predominantly ethnographic, exploring the nature of the teacher-student interactions, and teachers'experience of planning and implementing a representation construction sequence in astronomy, and their reflection on their experience and the outcomes for students. The data includes illustrative examples of student work. It also includes records of the research team's analysis discussions in which themes were identified and refined.

As mentioned previously there were four Year 8 teachers who taught a four-week teaching sequence in astronomy to 5 classes of boys (class size 28-30 students)..In exploring teachers' experience of the representation construction approach the following data generation instruments were used:

- Pre- and post-tests;
- Planning documents and teaching resources;
- Classroom video of one lesson of three of the teachers – the lesson was chosen by the teacher;

- Recorded, and transcribed, teacher and selected student interviews following the teaching sequence;
- Student artefacts, in particular, their project books which contained a record of their responses to many of the representational challenges as part of the representation construction approach;
- Recorded, and transcribed, conversations among the Deakin CRISP team and teachers in planning meetings prior to the teaching sequence and every week of the teaching sequence; and
- Whole day review with CRISP researchers and teachers that involved studying student work and selected video segments of the teachers. The workshop review also included discussions about the teachers' perceptions of the representation construction pedagogy in relation to their practice. The review was recorded and transcribed.

The principles of the representation construction approach, described above, were used as an analysis framework to interpret the features of teacher student interactions, to explore the particular ways in which these principles played out in the astronomy sequence and the fidelity of these teachers' work to the approach. Teachers' perceptions of the approach, of its particular affordances, and of student learning gains, were analysed through the identification of themes that were developed from the interview and workshop discussion data, through discussion amongst the research team and in collaboration with the teachers.

The study design

Salsa College is an all-boys metropolitan Catholic secondary school in a middle class area of an Australian city, with student enrolment around 950. There were four teachers (Alice, Suzy, Kate and Jaz)[2] who taught five Year 8 classes (class sizes of 28-30) the topic of astronomy

[2] Pseudonyms are used for the school and teachers cited in this chapter.

over a 4-week teaching sequence. There was 160 minutes of class-time each week that consisted of an 80 minute lesson and 2 x 40 minute lessons. One of the classes was special entry (high academic achievement) taught by Alice; two of the classes were taught by Kate and the other two classes by Suzy and Jaz. All teachers were quite experienced, Suzy and Jaz had taught at Salsa College for several years, Alice was in her first year at Salsa College and Kate was in her first Term at the school. The topic of astronomy dealt with explanations associated with such phenomena as day/night cycle, phases of the moon, seasons, gravity and eclipses. The intention was to address the new Australian Curriculum: Science (ACARA 2010) and so the content of this topic matched this curriculum.

The teachers were provided with curriculum resources and professional development that was delivered in various forms by the Deakin CRISP team. Each of the teachers was given curriculum resources that were based on the findings from the teaching of this topic using the representation construction approach in one of the schools which took part in the original RILS project. These resources consisted of pre- and post-tests, written descriptions of various activities that illustrated the representational construction approach, examples of student work from the RILS project and digital resources in the form of PowerPoint presentations with embedded interactive simulations and video.

In addition to these resources Alice had already had prior knowledge of the representational construction approach through participation in a 3-day state-wide professional learning program that had a focus on this approach and was funded by the Victorian (Australia) Department of Education. Suzy and Jaz had undertaken a 2-hour after-school workshop delivered by the CRISP researchers to the science staff at Salsa College. In both the state-wide professional learning program and the workshop importance was placed on the University experts modelling this approach.

The support given to the teachers also consisted of weekly meetings during the teaching sequence where the CRISP researchers and teachers had reflective discussions as to the previous week's teaching in addition to planning the future week's teaching. The four teachers involved in the CRISP project worked closely with the CRISP researchers in unit development, but ultimately were responsible for the operation of the ideas in the classroom.

The Representation Construction Approach in Teaching Year 8 Astronomy

This section describes the four-week astronomy sequence as it occurred at Salsa College in the four teachers' classes. Links are made between the various activities and the key elements of the representation construction approach, to clarify the central features of the pedagogy.

In enacting this approach importance needs to be given at the planning stage to the determination of the key concepts that underpin the topics to be taught [***Principle 1a***]. These concepts are expressed as statements of understanding couched in language readily understood by the students. At the planning stage of the topic the CRISP researchers worked with the Salsa teaching in developing a set of key concepts that would underpin the teaching and learning of astronomy. For example:

- Day and night are caused by the Earth turning on its axis every 24 hours,
- The seasons are caused by the changing angle of the sun's rays on the Earth's surface at different times during the year (due to the Earth revolving around the sun). This means for observers from Melbourne:
    - The midday Sun in summer is higher in the sky than the winter Sun. It will never be directly overhead at any time of the year.
    - The hours of daylight are longer in summer than in winter.
    - The average temperatures are higher in summer than in winter.

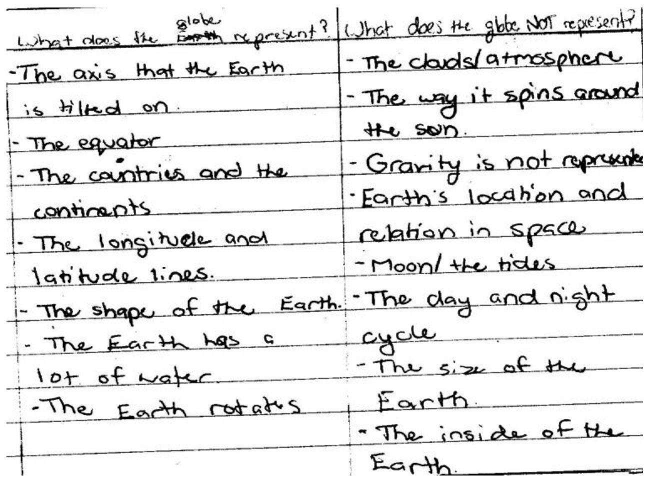
The epistemological position underpinning our approach is that concepts such as these, traditionally couched in formal verbal terms, need to be understood as standing for a set of interlinked representations and practices. Thus, these statements of understanding guided CRISP researchers and Salsa teachers in the development of the representational resources and strategies to use in teaching each concept. The statements also guided the teachers in developing a set of representational experiences that provided students with a coherent link between the concepts.

The teaching sequence began with pre-testing of the students' understanding of the key concepts. The administration of pre-tests were not common at Salsa College but the prevalence among the students of common alternative conceptions exposed by the pre-test, consistent with the student conceptions research literature, informed the teachers' classroom strategies. This is illustrated by the following comments by Alice:

> *I asked the ones, that I knew had misconceptions, to put them up on the board. And then we kind of discussed, alright, so now we know this is the case, do we have to change these representations? And it was really good, because then they would go "Yeah we do actually, this needs to be changed." ... we weren't pretending like they had this blank slate and they'd never seen astronomy before. They already had ideas, that we kind of – half the battle was challenging them, more so than teaching them new content.* [Alice]

The teaching sequence for each of the classes proceeded with a critique of the globe as a canonical representation of Earth in space. Students were given the task to determine those characteristics of Earth that were represented by the globe in addition to determining those characteristics of Earth that were not represented by the globe [***Principle 2d***]. Once lists were compiled by the students (see Fig. 1) they formed the basis of a whole class discussion.

From these discussions the phenomenon of the Earth's tilt was discussed. Analysis of the video record of class discussions, and records of discussions with teachers in review meetings, indicated that most students felt the tilt was with respect to the vertical thus explicating an earth frame of reference rather than considering the space frame of reference of the earth. One teacher resolved this by making explicit references to the two frames of reference. This was done by placing the students into a space view and modelling Earth's rotation around the sun with a globe revolving around a student representing the Sun; the Earth's tilt with respect to its plane of orbit of the sun was made apparent [***Principle 2a***].



What does the globe represent?	What does the globe NOT represent?
-The axis that the Earth	- The clouds/atmosphere
is tilted on.	- The way it spins around
- The equator	the sun.
- The countries and the	- Gravity is not represente
continents	-Earth's location and
- The longitude and	relation in space
latitude lines.	- Moon/the tides
- The shape of the Earth.	- The day and night
- The Earth has a	cycle
lot of water	- The size of the
-The Earth rotates	Earth.
	- The inside of the
	Earth.

Figure 1 Year 8 student's critique of a globe as a representation of Earth in space

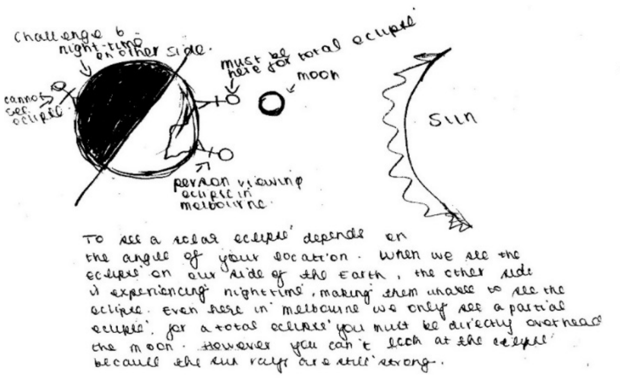
The teacher then provided the students with another space frame of reference getting them to use the globe as a reasoning tool to predict observations made from Earth from a space frame of reference. A small figurine was affixed to the globe to represent an observer on Earth located in Melbourne (Australia) and a ball was used to represent the Sun. For a particular orientation of the globe with respect to the ball the students were asked:

1. Which way does the Earth spin?
2. For the position of the figurine on the globe as representative of an observer on Earth:
    a. what time of the day is being represented?
    b. where else on Earth is it the same time of day?
    c. what is the season?

In answering the first question one student rotated the globe and reasoned that as the Sun shines on the East coast of Australia first then the Earth must rotate in an anti-clockwise fashion. Following this activity, and in subsequent lessons, each pair of students was given access to a mini-globe and a small, but powerful, Light Emitting Diode (LED) torch. These were to be used as a reasoning tool to gain understanding of astronomical behaviours such as the day and night cycle, eclipses, seasons and phases of the Moon. For example, Figure 2 shows a student response to a representational challenge to explain in their journals why when some observers on Earth can experience a total eclipse others cannot. The students used the mini-globes and LED torches when undertaking this challenge [***Principle 3a***]. This figure is typical of higher quality student representations. Note, in the figure, the coordination of text and image, the sophistication of the reasoning, and evidence of strong, and distinctly individual engagement with the challenge task.

The teacher saw the use of the globe and torch as a tool to facilitate students' space-centric explanations of geocentric observations of astronomical phenomena [***Principle 3, 1a, c***]. Alice commented:

> *And I think that the biggest thing, that worked really well, was the use of the globes. It had them all having the globes and actually having something physical to play with, actually made a lot of difference, in just those first few kinds of concepts, that usually, it's hard for them to get their heads around.* [Alice]



To see a solar eclipse depends on the angle of your location. When we see the eclipse on our side of the Earth, the other side is experiencing night-time, making them unable to see the eclipse. Even here in Melbourne we only see a partial eclipse. For a total eclipse you must be directly over the moon. However, you can't look at the eclipse because the sun rays are still strong.

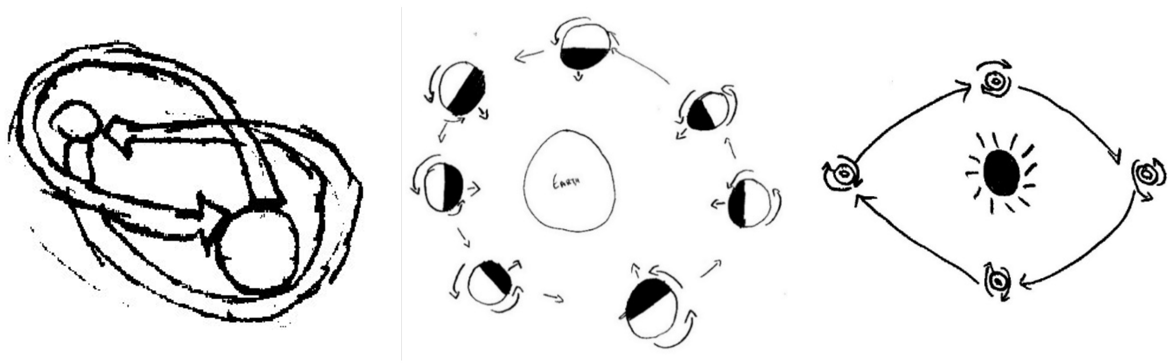
Figure 2 Year 8 student's response to the total eclipse challenge

The relative motion of the Earth, Moon and Sun in terms of rotation and revolution give rise to a variety of phenomena on Earth such as the day and night cycle and phases of the Moon. In exploring the motions of rotation and revolution the teacher gave the students a series of representational challenges [***Principle 1***]. The first challenge was for a pair of students to demonstrate, through an embodied representation, their understanding of rotation and revolution. Following a class discussion that evaluated the representation all students came to an agreed understanding of these movements and the need for a central axis for rotation and a central point for revolution and linkage of these terms with the everyday language of spin (rotate) and orbit (revolve).

The teacher then provided the students two representational challenges [***Principle 1***]. These were:

1. Is it possible for two celestial objects to revolve about each other?
2. The Moon always has one face to the Earth. Over one month the Moon undertakes one complete revolution of the Earth. During this time does it also rotate and, if so, how many times?

The students found that answers to these challenges could only be obtained through role-play [***Principle 1b***]. The evaluation phase of each challenges was undertaken as a whole class discussion. For the first challenge, to which the answer is yes, the teacher made a link to binary star systems where this phenomenon is found. For the second challenge, many of the students were quite sceptical in the beginning as to whether the Moon rotated but by undertaking the role play they found evidence that the Moon does indeed rotate, making one full rotation each month. This evidence was the observation that in undertaking one full revolution the student representing the Moon observed each wall of the classroom just once, as they would if they rotated in a fixed position. Figure 3a shows evidence of a third challenge given to the students whereby they were to pictorially represent two objects revolving about each other. In this task students were expected to re-represent their 3D role-play representation of revolving celestial object into a 2D form [***Principle 3b***]. The teacher had a common practice that in most lessons some time was allocated at the end of the lesson for the students to represent in their journals something they had learned that lesson. Figure 3b shows one student's representation of the motion of the Moon whilst Figure 3c shows another student's representation of rotation and revolution of the Earth's motion about the Sun. These three representations were selected to be typical of student work. They constitute a representational re-description of the role play that was used to establish the distinction between rotation and revolution. In each case the representation engages seriously with the representational challenge, in ways that are distinct from standard astronomical figures found in school texts.



3a Revolving Suns **3b** Motion of the Moon **3c** Motion of Earth

Figure 3 Year 8 representations of rotation and revolution of celestial objects

In enacting a representation construction approach students and teachers are involved in a continuous, embedded process of assessing the adequacy of representations, and their coordination, in explanatory accounts [***Principle 4***]. In these classes public display and critique of the students' representations either at the whole class or small group level was an essential component to the representational challenges that were given. Kate and Alice commented on their strategies for doing this, and their effectiveness:

> *I photocopied a whole lot of different kids' representations which were passed around… they had it for a minute and then it got passed on. They had to evaluate the representations …that got them thinking oh hang on, that doesn't show that. I think it does, but it actually doesn't but I think it's good.* [Kate]

I'd ask for someone to come up and then I'd ask for someone who had something different than they had up, to come up, so we ended up with like 3 or 4 different ones and then we'd look at which one did the best… and then they just debate them. [Alice]

An example of a representational challenge for the students (see Fig. 4) was to represent in a drawing the phenomenon that the noon day Sun does not go directly overhead during winter from the location of Melbourne (Australia). This challenge followed a class demonstration and discussion using 3D models representing the phenomenon. Each of the representations draws on different and distinct semiotic resources to indicate the height of the sun above the horizon.

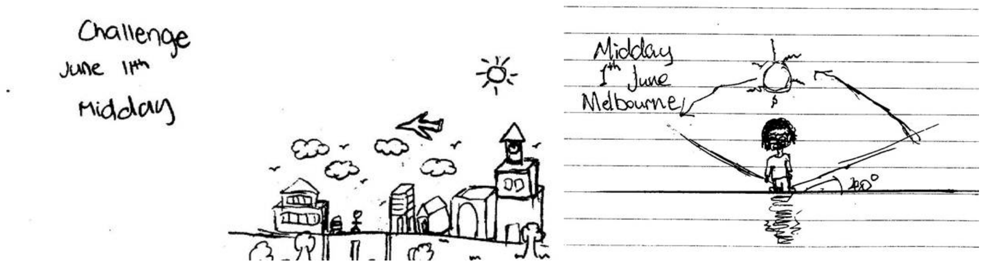


Figure 4 Year 8 students representations of the noon day Sun in winter from Melbourne

The assessment of the adequacy of representations is a key feature of the representation construction approach. Part of the purpose is to develop students' meta-representational competence (diSessa, 2004). This occasionally extended to assessment of canonical forms found in science texts and on the internet. Figure 5 below shows a student's journal entry of a task that involved the critique of two textbook representations of the phases of the moon [***Principle 4***].

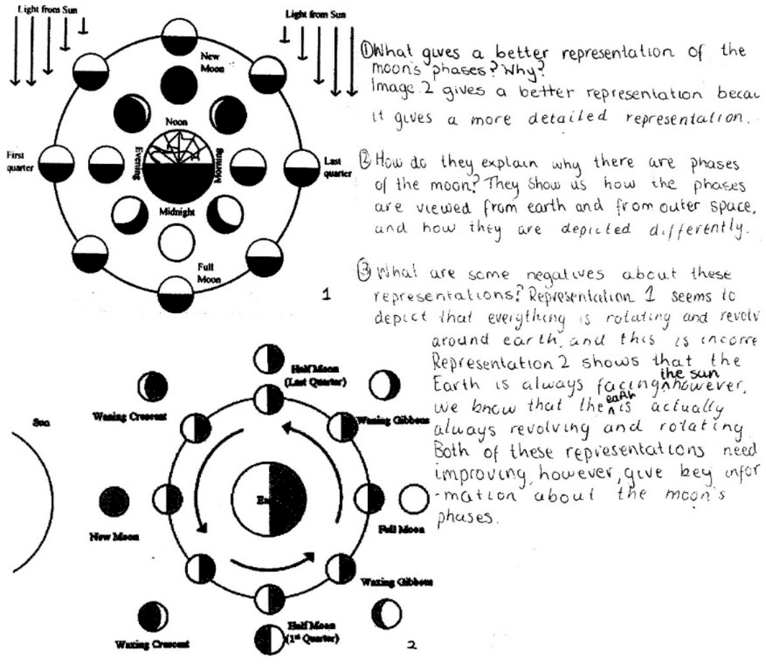


Figure 5 A Year 8 student's critique of two textbook representations of phases of the moon

In interviews and during meetings teachers frequently commented that the ample provision of space given for students to respond to representational challenges and paper-based test questions afforded the students the opportunity, and permission, to express their understanding in a variety of representational forms that are distinct in fresh ways from diagrams that are copied from texts or from the board. This was supported by analysis of student representational work. For example, Figure 6 provides four students' responses to a topic test question where they were given the context that one of the moons of Jupiter was found to rotate and revolve around the planet and asked to explain the difference between representation and revolution. Again, each demonstrates serious attention to the task, and focused reasoning. The representations demonstrate a variety of semiotic resources; the first two, for instance combine text and drawing. They are individual, and distinctive.

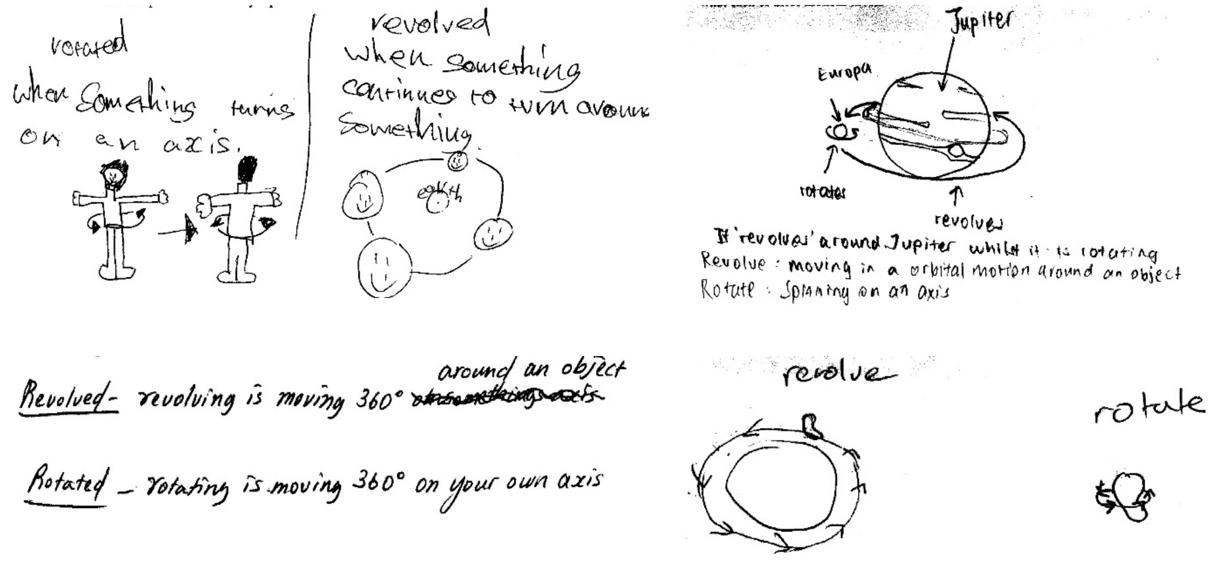
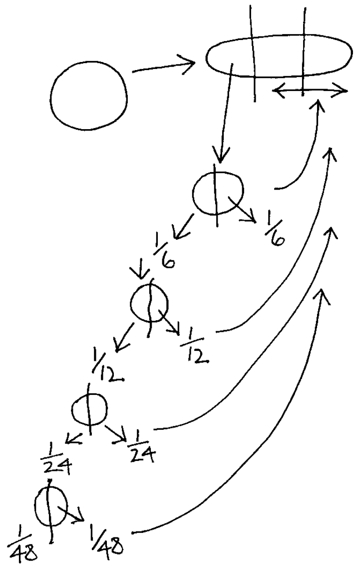


Figure 6 Year 8 students' explanations of rotation and revolution

The teaching sequence placed importance on developing students' concepts of size and distance of celestial objects. In constructing a solar system model on the school oval that involved students representing the Sun and the planets the class discussed the meaning of a 'year' on planets other than the Earth and speculated how far away from the school oval might the nearest star be located. In another activity students were challenged to represent the relative sizes of Earth and Moon given a handful-sized lump of plasticene. Evidence from the students' journals where they recorded their predictions showed that very few students constructed models that reflected the actual relative sizes of the Earth to the Moon. Most overestimated the size of the Moon and so the teacher gave written instructions (Fig. 7a) for students to construct accurate models. Most students were unable to undertake the task from written instructions so a representational need was established [***Principle 2b***] after which the teacher developed the diagram (Fig. 7b) shown which the students were able to follow. The next challenge for the students was to represent the separation of their models of Earth and Moon. All the students underestimated the distance which led the teacher to show an accurate model of the Earth, Moon and Sun both in relative size and distance. This model was then used to represent the monthly motion of the Moon around the Earth. This model gave the students a plausible representational form to explain why lunar/solar eclipses do not occur every month and offset textbook diagrams which suggest such occurrences occur regularly, since distance and scale are often not represented in the diagrams (Dunlop, 2000).

Relative size of Earth and Moon

1. *Join the two spheres together and roll the plasticine into a sausage shape;*
2. *Divide the sausage shape into three equal parts and then join two of the parts together.*
3. *Divide the third piece of plasticine into two halves, keeping one half in your hands and adding the other half to the larger piece of plasticine.*
4. *Divide the smaller piece into two, keeping one half in your hands and adding the other half to the larger piece of plasticine.*
5. *Repeat step 4*
6. *Repeat step 4*
7. *You should now have one small piece and a large piece. The small piece represents the Moon and the small piece represents the Earth.*



7a Written instructions

7b diagrammatic instructions

Figure 7 Instructions for creating a plasticene model of Earth and Moon

Main Findings

The main findings, following the research questions, relate to teacher perceptions of the distinctive features of the inquiry approach, it's role in assessing student understanding, and the impact on student learning. These major themes emerged over time, from analysis interviews and records of workshop discussions.

Teacher perception of the inquiry approach

The teachers perceived the representation construction approach as one in which the teacher might effectively implement an inquiry approach that moves beyond textbook teaching. Core features include the freedom from text-book domination that the inquiry approach brings, and the way that the approach is distinct from open inquiry in the way it focuses on conceptual learning:

- *Oh it's just reinforced that sometimes textbooks aren't the answer to all science teaching and if you mix it up I think that's the best approach rather than flogging this textbook idea. I think if you can bring something like this inquiry based learning as a different approach I think that's only going to benefit the kids' learning* [Jaz].

  I think it's given us an actual tangible way to do the inquiry base that's an easier way for most staff to sort of like cause when we talk inquiry base they think open ended the kids are going to be all over the shop hey whereas this kind of gives them that ability to have inquiry learning but in a different way [Kate].

The teaching approach was perceived to be effective through the active engagement with materials and with problem tasks: "*because they're learning by doing it they're not just rote learning or trying to remember facts* [Kate]" and the interactive nature of the tasks: "*having to explain it to someone else or to put down what they know* [Jaz]".

Formative Assessment

The teachers used the information gained from the pre-tests in their teaching as is illustrated by the following comments:

> *…we weren't pretending like they had this blank slate and they'd never seen astronomy before. They already had ideas, that we kind of – half the battle was challenging them, more so than teaching them new content.* [Alice]
>
> *I did deal with the topics that they had the most trouble with* [Jaz]

The students used project books, which contained blank pages that encouraged visual forms of representation. The students used their project books more as learning journals that facilitated the use of drawings in recording not only what they had learned but their developing ideas (see Figure 8 for examples). The visual representations provided the teacher with ready insight into students' thinking. One of the teachers, Alice, commented in an interview:

Immediately by looking at their representations, I know, okay those boys have got it and those boys are on the right track but those haven't fully kind of understood (Alice)

But the books just having the blank page, I think sometimes, it's just all text, that we kind of forget how much the use of those representations and diagrams can really help in Science, so it was a good reminder. (Alice)

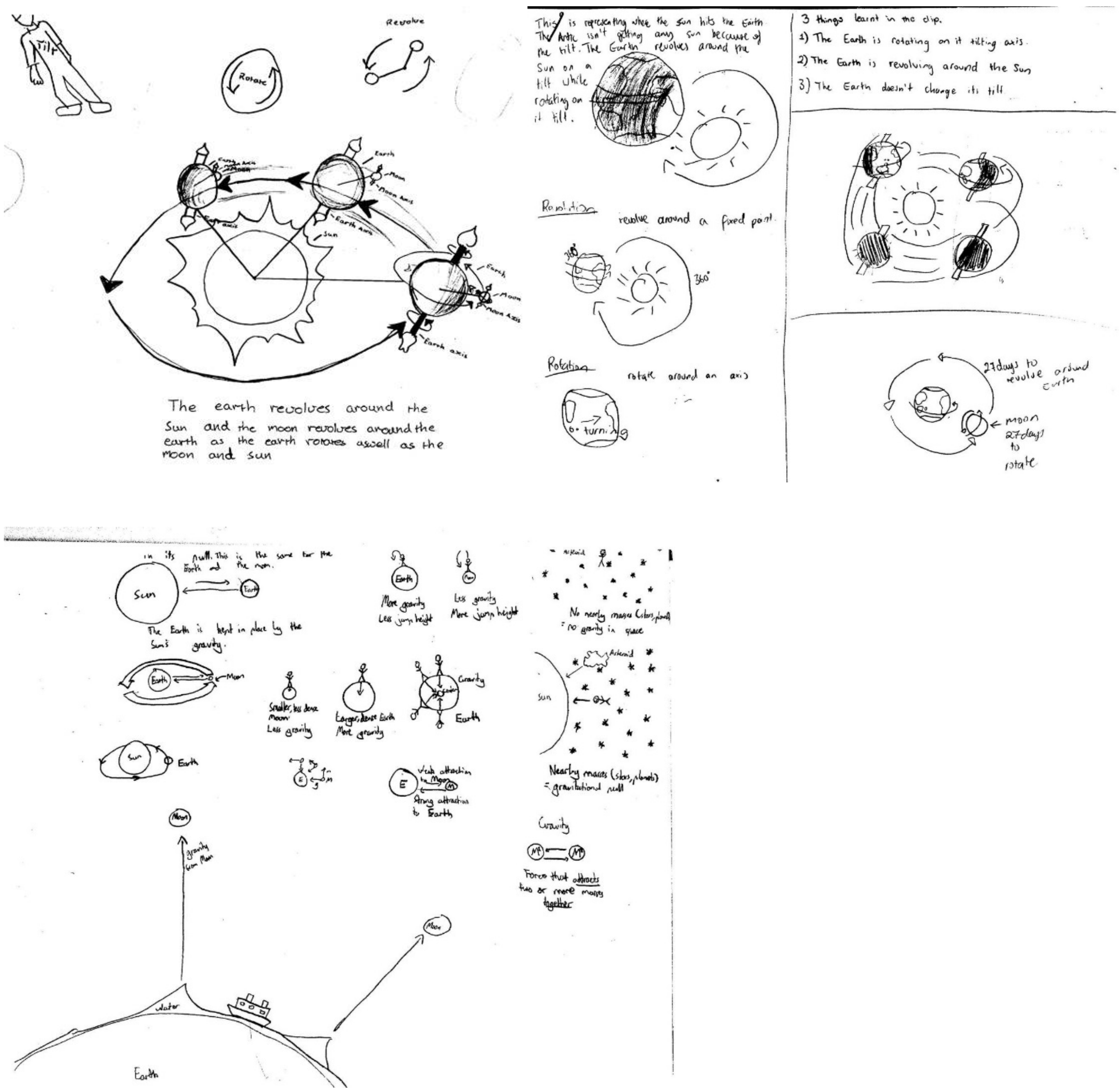


Figure 8 Examples of students' learning journals entries

Figure 8 shows three images from students' journals, which are typical of higher end representational work. While a formal analysis of these representations has not been undertaken, each illustrates the productive nature of representation construction in relation to features such as: 1) the coordination of multiple representations that show different perspectives brought to bear on a challenge, 2) the quality of reasoning, and particularly spatial reasoning, that is evidenced, and 3) the coordination of image and text that is characteristic also of scientific discovery processes (Gooding, 2004, 2006).

The Salsa teachers had introduced the journals, in consultation with the researchers, as an innovation designed to encourage students to engage seriously with representational work. In meetings they frequently described how the students were more willing to use their journals to reflect on their learning than had been previously the case with text journaling. As Kate pointed out:

> *…they seemed more willing to go back over their work and look back at their past stuff as well…And I don't think they do it very well if it's just written stuff, and they had a sense of ownership over it which was good (Kate)*

Student learning

Pre- and post-testing of the students revealed substantive gains in learning. Table 1 indicates substantially improved students' results to 13 multiple choice questions on the pre/post-tests. The test was a recognised instrument developed by Trumper (2001), and in particular was used by Kalkan and Kioglu (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, using the normalised gain index, <g>, as a measure of comparison of pre- and post-test results. <g> is a measure of the ratio of the actual average student gain to the maximum possible average gain: <g> = (post% - pre%) / (100 – pre%), as reported by Zeilik, Schau and Mattern (1999). Gain index values can range from 0 (no gain achieved) to 1 (all possible gain achieved). For multiple choice questions, a gain index of 0.5 for an item indicates that for instance if 40% of students in the pre-test answered the question correctly, 70% answer correctly in the post test, being 0.5 of the possible gain from 40% to 100%. The mean gain reported by Kalkan & Kiroglu (2007, p. 17) was described as a "respectable 0.3". In contrast the mean gain for this study was significantly higher at 0.52. While the conditions may be different for the two groups, the comparison indicates a very strong gain in understanding of key astronomy concepts attributable to this guided inquiry approach.

Table 1: Correct answer ratio and gain index (<g>) according to pre- and post-test results for two studies

		Year 8 Students N=125			Kalkan & Kiroglu (2007) study		
	Item	Pre-test	Post-test	Gain	Pre-test	Post-test	Gain
		% correct		<g>	% correct		<g>
1	Day-night cycle	9	91	0.80	91	93	0.22
2	Moon phases	30	55	0.36	23	30	0.09
3	Sun Earth distance scale	19	60	0.44	18	22	0.05
4	Altitude of midday Sun	8	56	0.53	29	39	0.14
5	Earth dimensions	12	57	0.44	5	14	0.09
6	Seasons	8	28	0.23	54	82	0.61
	Relative distances	33	62	0.49	46	71	0.46
	Moon's revolution	27	82	0.72	49	60	0.22
7	Sun's revolution	60	85	0.70	61	77	0.41
8	Solar eclipse	18	41	0.32	26	42	0.22
9	Moon's rotation	15	55	0.48	13	28	0.17
10	Centre of universe location	61	76	0.48	65	88	0.66
11	Seasons	38	89	0.81	67	88	0.64
			mean <g>	0.52		mean <g>	0.31

In addition to these multiple choice questions there were extended challenges where students were encouraged to construct representations to respond to a question. In a reflection on the different ways in which the students responded to these open-response test questions the teachers commented:

In their test answers if we gave them the space they would perhaps do a diagram to help with explanation or we might say use representation, they didn't just stick to the words [Jaz].

And it was valued by those boys that do like to draw…the questions allowed them to represent their knowledge in multiple ways [Alice].

The students are not having to just write down a definition they are having to 'show' a definition through the use of representations [Kate].

Conclusions

Evidence from this study supports the claims made from our previous research (Tytler et al., 2013b) that a guided inquiry, representation construction approach leads to enhanced student outcomes and engagement with reasoning and ideas. The sequence has demonstrated that in this case of teaching astronomy:

- students have experienced enhanced learning outcomes, as evidenced by the results on the multiple choice test, by teacher perspectives, and by inspection of the quality of entries in students' journals; and
- the sequence resulted in sustained engagement with ideas, as evidenced both by teachers' assertions and again the quality and detail in students' journal entries, which were both detailed, and focused.

The astronomy sequence described in this chapter illustrates a number of aspects of our sociocultural theoretical perspective, described in the introduction, and provides insight into some of the positive outcomes of the approach.

We argue that the conceptual change challenges accompanying reasoning and learning astronomy, which fundamentally involve the capacity to accommodate the relationship between earth and space perspectives on sun-earth-moon relations, are fundamentally representational in character (Tytler & Prain, 2013). As this astronomy sequence illustrates, the challenge involves learning to re-describe and coordinate a range of representations/models through which we visualise spatial relations.

On this matter, a key task in planning the unit with the teachers was identifying the key conceptual challenge: that of developing the representational resources that enabled students to model the relation between astronomical objects, and shift between earth and space perspectives. The figures illustrating student representational work illustrate the way this key challenge underpinned the tasks given throughout the unit. Even the plasticine modelling exercise involves the generation of an embodied sense of relative size and distance of the earth and moon. The rotate-revolve task also is a good illustration of how students were challenged to shift perspectives from their embodied sense of planetary movement to link with features of binary star or earth-moon relations. Most of the other figures were explicit examples of this challenge to coordinate representations of earth and space perspectives.

An important insight we have gained through our work, and that students are led to appreciate, is that any representation is inevitably partial, and fundamentally an approximation. We emphasise that 'fit for purpose' is an appropriate aim for representations that students generate, rather than 'correctness'. Thus, the discussion of what a globe represents (Figure 1) emphasises the partial and selective nature of any representation. A map cannot fully represent the territory it purports to relate to. The varied and mostly insightful responses to the question concerning the difference between 'revolve' and 'rotate' (Figure 6) illustrate the imaginative variation in representations that equally satisfy the challenge to articulate this abstraction. The multiple representations in students' journals (Figure 8) illustrate how multiple representations are needed, including text, to satisfactorily solve problems and communicate explanations. Thus, the students' work illustrates this fundamental aspect of knowledge and reasoning in science.

The revolve-rotate sequence illustrates a further important construct that informs our work; that of the affordances of different representations and modes to support explanatory work

(Prain & Tytler, 2012). Thus, the role-play concerning the rotation of the moon focused students' attention on how the moon lined up at different points in its orbit, whereas the abstracted diagrammatic version (Figure 3b) reifies this motion's temporal sequence to establish the spatial pattern. The movement from role-play to diagram, or between different diagrammatic perspectives, and text, illustrates the importance of representational re-description and coordination in problem solving and explanation in science.

An important aspect of this approach is the way in which formative and summative assessment is facilitated. In terms of formative assessment, students' representational work in journals, or in the public space, allows teachers to monitor and respond to their varied and shifting understanding. The approach where students are challenged to represent and discuss their representations publicly naturally involves ongoing interactions between the teacher and students concerning their ideas. Further, teachers have often expressed the view that students' drawn or modelled or embodied representations provide insights into their thinking that are sharper than tends to be achieved through text. This can be understood as an aspect of the affordance, as "productive constraint" (Prain & Tytler, 2012), of modes, which forces specificity on student representational work that places demands on reasoning (for instance in Figure 2 decisions needed to be made concerning relative size and position of the earth and sun, and placement of observers) and correspondingly exposes thinking for the teacher to respond to. In terms of summative assessment, we have found that designing post-tests with blank spaces where students are encouraged to represent multi modally can encourage high-level responses that allow judgements about depth of understanding. On the other hand, further research is needed concerning how such varied and complex responses such as those of Figure 6 can be reliably assessed.

In interpreting the reasoning and learning that occurs as students make sense of their experience through the representations they are introduced to, or construct, we draw on Peirce's triadic model of meaning making (Figure 9). The process by which students achieved an understanding of a solar eclipse for instance involves the construction of a representation of the sun-earth-observer system (Figure 2) and the alignment of this with its referent, the experience of eclipses, in order to make meaning. Misunderstanding or partial understanding occurs when there is incomplete coordination of the representation with its referent, or between successive representations needing coordination for complex explanations. Reasoning is distributed across multiple modes, such as visuo/spatial, embodied, and verbal representations.

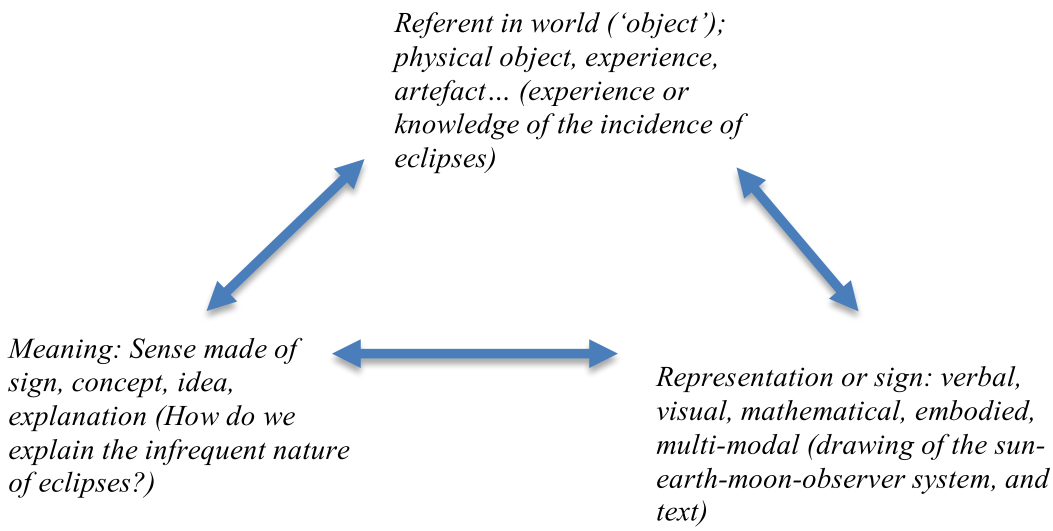


Figure 9 Peirce's triadic model of meaning making

Thus, we argue that reasoning and learning inevitably involve representational work, and that representations are active mediators in the learning process, and a fundamental feature of the structure of knowledge. The development of a representational 'vocabulary' and the processes of creating and coordinating representations, are part of the process of induction into the disciplinary literacy of science. The astronomy sequence described in this chapter provides an illustration of how this can be effectively supported through a guided inquiry process.

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