Chapter 7
Reasoning Through Representations

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Introduction

There has been increasing interest and research into the role of representation and modelling in teaching and learning science, as in other subjects. Following Lemke's (1990) early work on the multi-modal nature of teaching and learning in science classrooms, researchers have focused on the role of representational interpretation (Ainsworth 2006, 2008; Gilbert 2005) and construction (Carolan et al. 2008; Tytler et al. 2013b) in learning, in problem solving (Kozma and Russell 2005) and in practicing science in school classrooms (Ford and Forman 2006; Manz 2012). However, work remains to be done to better understand the detailed principles underpinning the sequencing and coordination of representational work in teachers' practice.

As part of the EQUALPRIME video captured data we have examples of sequences in astronomy in Australia, Germany and Taiwan. In this Chapter we use these data to examine the representational coordination practices of these expert teachers from the three countries, in order to establish principles of sequencing and coordination of representation attaching to expert practice. The analysis has the advantage of exploring this issue in systems with quite different curriculum framing and resource support, and arguably different pedagogical traditions and values.

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In this way, we will explore the possibility of general principles emerging that transcend these particular cultural contexts. The question of the nature of quality teaching and learning will be taken up in Chap. 10.

Representation and Learning in Science

There is growing recognition of the centrality of representations in reasoning and learning in science, and a developing tradition of research around the multimodal representational practices of teachers and students in science classrooms. Recognition of the material nature of learning and knowing that underpins the discursive practices of the science classroom (Kress and van Leeuwen 2006; Lemke 1990, 2004) follow similar insights into the knowledge building practices of science as involving the generation and coordination of multiple and multimodal representations (Gooding 2005; Latour 1999; Nersessian 2008). Learning science in school is increasingly seen as a process of enculturation into the discursive practices and specific literacies of the subject, through which the scientific community generates and justifies claims about the natural world (Lemke 2004; Moje 2007). Kress and colleagues (2001) have studied science classrooms from a socio-semiotic perspective to show how knowledge is built through the enactment of scientific discursive practices using a range of visual, action (experiments, demonstrations and gestures) and verbal and written representations.

Research has focused on the challenges for students in interpreting and coordinating the multimodal representations that underpin instruction in science classrooms (Ainsworth 2008; Gilbert 2005), and on the ways in which students can be guided to construct and refine representations as part of learning to reason with these epistemic tools (Greeno and Hall 1997, Lehrer and Schauble 2006; Tytler et al. 2013b). Kozma and Russell (2005) have shown how developing expertise in problem solving in science involves learning to flexibly access and coordinate a range of representations as part of reasoning.

The way representations are used in classrooms to best support quality learning has been the subject of an important strand of research. In his research on visualisation in chemistry education, Gilbert (2005) has emphasised the need to coordinate representations at the macro, meso and micro levels in order to build solid understanding. Researchers (Hackling et al. 2013; Jewitt 2007, Kress and van Leeuwen 2006) have drawn attention to the way sequences of representations are enacted and brought to life by teachers using gesture and talk. Ainsworth (2006) developed a framework for learning with multiple representations that attempted to build advice around the design parameters, the functions, and the cognitive tasks attached to different representations. She (Ainsworth 1999, 2008) cautions that learners can fail to exploit the advantages of multiple representations if they are inappropriately used in the classroom. She describes the different functions that representations serve, including constraining interpretation (Ainsworth 1999), and develops a set of principles to guide their use. Tytler et al. (2013b) point out the partial nature of any representation and the need to coordinate a number of representations in order to achieve understanding, explain, or problem solve in any scientific domain. Prain and Tytler (2012) describe the power of particular representations and their modes to support reasoning in terms of their affordances, which offer a productive constraint on what is attended to, such that understanding is channelled in selective ways by each representation. There is evidence that representations actively mediate and shape knowing and reasoning (Tytler et al. 2013b) and play a defining, rather than a supporting role in the generation of understanding (Klein 2001; Tytler et al. 2009; Zhang 1997).

There is growing agreement on the way in which sequences of representational practices are central to effective teaching and learning in science and on how these can be viewed as a central part of an induction into the discursive practices of science. These sequences are seen as ways in which teachers enact scientific practice and talk representations into existence in ways understood by the scientific community. There is agreement also on the way representations channel and constrain attention in productive ways. While there is agreement concerning the role of multimodal representations in learning, and the importance of coordinating representational use, the principles by which expert teachers support students to link and coordinate representations is not well understood, beyond a need for gesture and talk to accompany them, and if there are such principles, whether aspects of them transcend different teaching approaches and cultural practices.

Access to comprehensive video data on sequences of lessons of expert teachers from these different countries and education traditions, on the same topic that is particularly rich in representational resource use, provided us with a source of data to explore these issues and address the research questions:

1. How do competent teachers coordinate representations to teach astronomy?
2. What are the verbal and non-verbal strategies used by teachers to support reasoning and establish meaning, during representational sequences?
3. How does the cultural context impact on teachers' strategies associated with representational use?

Method

This research sits within the broader EQUALPRIME project and draws on data sources including video capture of sequences of Grade 3–4 lessons in specified topics, interviews with teachers and students, and documentation of teaching resources and student artefacts. The current analysis concerns three sequences in Astronomy: a 15 lesson Taiwanese sequence on phases of the Moon, a six lesson Australian sequence concerning the movement of the Earth in space and the cause of day and night, and a five lesson German sequence on Earth, Sun and Moon relations to explain moon phases. The context for each sequence is described below.

Ms Grace is an Australian generalist elementary school teacher with 12 years of experience. She has a significant interest in teaching science but has no formal science qualifications. The Grade 3 curriculum outcome for Astronomy refers to the regular day and night changes caused by the Earth's rotation. In this sequence Ms Grace draws heavily on the unit *Spinning in Space*, part of the *Primary Connections* resource developed by the Australian Academy of Science, which has a strong emphasis on literacy skills as well as an inquiry focus built around the 5Es model (Hackling et al. 2007). In interview, Ms Grace emphasised active engagement of students in learning, and the value of group work in problem solving situations.

Ms Hong has been teaching for 14 years and a specialist teacher of elementary school science for 7 years. She teaches in a school in Taipei that has a special focus on science; astronomy in particular. The Taiwanese curriculum is very specific in its specification of topics, and is supported by detailed textbooks providing activities and resources, including digital resources such as images of the Moon and moon charts. In interview, Ms Hong emphasised the use of a variety of teaching strategies and contexts to achieve conceptual learning goals, and equip students for future learning. There are 27 fourth graders in the class.

Ms Petersen teaches at a government primary school (Grades 1–6) for 420 students in a southern suburb of Berlin which is dominated by middle-class families. The school has a special science profile called *Science from the Start*. The goal of this program is to foster an interest in natural phenomena and scientific explanations of these in all students from the very beginning of primary school. Younger students regularly visit outdoor science spaces; however, no extra science lessons outside of the regular subject area *Sachunterricht* are available. The teachers, though, are quite free to use the hours allocated for language training to include longer periods of language and discourse in other subject areas such as science.

Ms Petersen is a generalist teacher. She has a Diploma in Biology and a Master of Education for Primary Education. She was also trained as a science journalist. She has 5 years of experience working in schools and a special interest in teaching science. Prior to becoming a teacher at school Ms Petersen worked for several years in an outdoor science laboratory visited by school classes. In the class there are 27 children; 14 boys and 13 girls.

For the purposes of this analysis, a self-contained sequence was selected that focused on a linked set of modelling moves, such as modelling the moon phases to explain previous observations of patterns. In the Australian and Taiwanese cases this involved a discrete lesson. In the German case it involved tracking a sequence of representations over three lessons. The video record in each case was accompanied by time stamped transcripts; in the Taiwanese and German cases these were translated into English. The analysis was micro-ethnographic, identifying key conceptual/ representational moves made by the teacher, and moving sequentially through identification of the ways key features of the representations were established through interactive talk and gesture and active modelling, to the way each teacher framed the coordination between the representations to establish shared agreement with the class on the meaning of the representational sequence. Each video was viewed multiple times by the researchers to continually test the analytic model as it emerged, cross-checking against each case to identify commonalities and differences.

The focus of the analysis, as it developed, became:

- The key representational moves that were made by the teachers, to establish and then link the series of multimodal representations.
- The identification of the salient features of the representations and how these were emphasised and linked by the teacher.
- The strategies by which teachers supported students to reason about and through the representations.

The findings from the three cases are presented in turn.

Findings

The three case descriptions give a detailed account of the main representational moves the teachers made, with commentary on the salient features of each representation, as emphasised by the teacher, and the talk and gestures surrounding the representation designed to establish meaning within the narrative of the lesson. This is followed by an overview of the sequence and the devices used by the teacher to link the representations and weave a coherent narrative.

Case 1: Ms Hong's Sequence on the Moon Phases

Ms Hong, as described above, is a specialist teacher of science in an astronomy-focused school in Taipei that spans both elementary and secondary years. The school has extensive astronomical modelling equipment and runs a planetarium as a local centre for interest in astronomy. Ms Hong thus has had access to expert mentoring to develop her understanding and teaching approaches. The Taiwanese curriculum is very specific and well supported by text and digital resources, and Ms Hong follows the structure of this. Nevertheless, she spends an estimated 37 % of class time on material beyond the set curriculum, due to personal interest.

The lesson analysed for this paper is the 11th in a sequence of 15, in which she introduced a model to explain the moon phases that the students have spent considerable time observing, measuring and tracking on monthly charts.

In interview, Ms Hong expressed a strong belief in engaging students with science ideas through using a range of media, to equip them for future learning. She was very articulate in unpacking her design intentions for the sequencing of representations, and was able to refer to research literature to support her approach. She has recently completed a Master's degree in science education. In describing the rationale for the lesson she emphasised the role of models in bringing the immense scale of the universe down to a size such that students can understand its 'true face' and how the astronomical objects ‘work’. She was explicit about the way she drew students’ attention to the key points of each representational activity, to support efficiency in learning:

> … tell students the next activity, and what are the important parts they should observe carefully while watching the demonstration. This is to save students’ time when they try to find out the answers by themselves. (Interview with Ms Hong)

We describe each of the representational moves from Lesson 11 in turn, focusing on the way they are made sense of, and coordinated.

Representation 1: The Half-Lit Ball Model of the Moon

Ms Hong established that the Moon is visible through reflected light from the Sun and then introduced a polystyrene model of the Moon. She asked for predictions as to how much of the Moon will be lit when the Sun shines on it, and collected votes for a range of views ranging from one third, to all of the Moon. Students were thus prepared for focusing on the key, salient feature of the activity; the lit part of the Moon. She darkened the room, turned on a strong focused light to represent the Sun, and held the ball in front of it, encouraging students to leave their seats and move around to look at the ball from different perspectives to answer the question: How much brightness? Thus, students gathered around looking from different angles (Fig. 7.1), effectively establishing a space perspective.

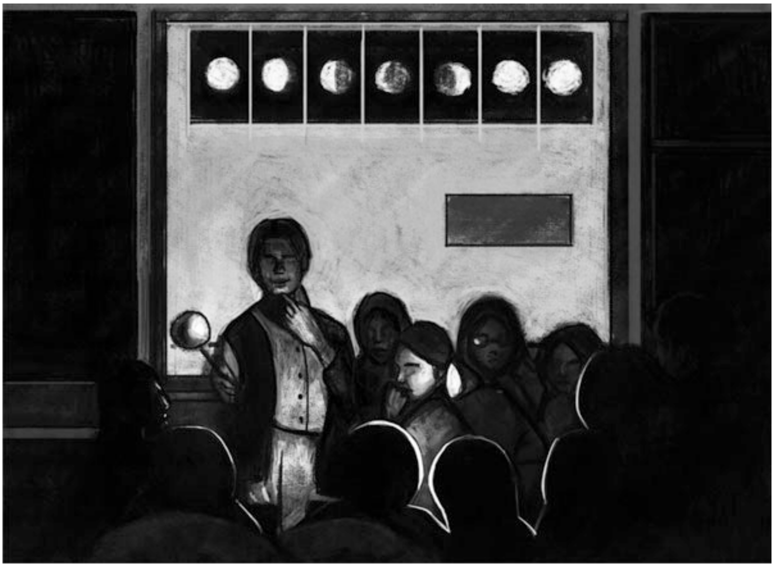

Fig. 7.1 Students gather around to see the lit moon from different angles

What students see is inevitably different from their different perspectives. Ms Hong introduced the idea of different perspectives on the half-lit ball and the possibility of an objective perspective from outside the system as a key feature of the representation.

Teacher: *Just now, you saw the Moon was bright on half side. Do you know what position that you stood that allows you to see the Moon like that?*

This dialogue was accompanied by her gesturing at the 'Sun' and 'Moon' and moving the Moon into different positions in a dramatic manner, to emphasise the Moon is half-lit no matter its distance from the Sun, or position. She then led them to an understanding that you cannot see what is happening, viewed from Earth, but you need to be in 'outer space' to be able to see the relationship between the Sun and Moon. This was accompanied by her mimicking the rotation of the Moon in a circular arc and pointing to the Sun, thus creating a space in the classroom occupied by these astronomical bodies, observed by students who were again in a position of 'outsiders'.

Teacher: *What position do you need to stand on in order to see a whole Moon … and a whole Sun? Is it possible for you to see when the Sun shines on the Moon if you are viewing from the Earth? And feel like this when the Sun shines on the Moon?*

The students assert that this is impossible. She then introduced the idea of 'astronauts' occupying a viewing position out in space, and that no matter what position (she gestures to various students round the class): "You will always see the side that is bright if it is facing the Sun".

In this sequence the half-lit ball becomes a scientific representation through a number of deliberately structured devices. It is not self-evidently a model of the Moon but gains its representational status through the classroom talk that first primes students to focus on the ball reflecting light from the Sun and the salient feature which is the extent to which the Moon is lit, the sun-moon position in relation to the lit part, and the dependence of its appearance on the perspective of the observer. In establishing these features, Ms Hong used gesture for emphasis, and to confine the sun-moon system to a limited space in relation to the students in the classroom as observers. The classroom space and positioning of the students were also used to establish the importance of perspective and the need to distinguish particular perspectives from a positioned observer to an 'outer space' or 'astronaut' perspective which involves being able to move around in space to see how the lit half always faces the Sun. During this entire sequence a projected display of moon phases was part of the backdrop.

Representation 2: 2D Drawing of the Moon

Students then drew the Moon on paper and were guided to use the convention of black and white to represent the visible and not visible parts. The teacher then demonstrated the drawing on the board establishing the abstracted representational convention of the view of the Moon from ‘outer space’. Interestingly the teacher drew the Moon in reversed colours, with white chalk on a green board, which presented an additional intellectual challenge for the children. This drawing was positioned next to the projected Moon phase images, linking the drawing convention for a first quarter moon with images of the Moon as seen from Earth, and the 3D model they had just investigated.

Representation 3: 3D/4D Role-Play of Moon Orbit and Phases

Ms Hong demonstrated the role modelling of the Earth and Moon, moving the ball, representing the Moon, 360° around her head, pausing to describe “using the Moon to block the Sun” and tapping her head (in this model the head represents the Earth and the perspective of the lit moon is as seen from earth) to say “you are the human on earth”.

She then arranged a subset of the class into groups, each with a light source and polystyrene ball. She emphasised the distinction between the ‘humans on earth’ perspective of the person at the centre of the Moon orbit who is holding the ball at arm’s length, with others in the group as ‘aliens’ or ‘astronauts’ looking on from outer space. She instructs: *“Pay attention to the bright part of the Moon. Is it becoming more and more, or less?”*

She then talked the groups through the role play, managing their ‘noticing’ at each of four positions representing new, full, first and third quarter moons, and contrasting the ‘human on earth’ and ‘astronaut’ viewpoint.

Teacher: *Hence, the people who are sitting in this position will be in the role of humans from Earth … But – you have not stood in this position. What kind of people are you?*
Student: *I am the alien!*

For instance, they established that in the new moon position the Moon is dark, and she asked them “please write it down”. She then re-established that from the astronauts’ view, the Moon is bright on the far side, facing the Sun. Thus she managed each quarter in turn, getting students to change their position from ‘humans on earth’ to ‘astronauts’ so they each experienced the two perspectives. Through questioning she continued to establish how much of the Moon is bright, and which part is lit up in relation to the Sun (e.g., on the right).

Finally, there was a review and again writing to mark the key question and conclusion, and she flagged further thinking:

Teacher: *For the earthmen…have you noticed that on different positions....1, 2, 3 and 4, the (shapes of) the Moon you saw were different?*
Student: *Yes.*
Teacher: *Can you try to link that with the change of moon’s shape (in a month)? Let’s write that down (keep as something we need to work on later)*

Ms Hong established the salient features of the role play representation very deliberately using questioning and managing the students' role plays very carefully, these being the changing moon shape (introducing the fourth dimension of time) as seen from Earth linked to position in the orbit, and the consistent outer space perspective. She links with the previous representation using the 'astronauts' and 'humans on earth' verbal cues to signal once again the different perspectives. She managed the link between the role-play situation of a darkened moon with the new moon phase, and finally she asked the students to link what they had just experienced with the phase sequences of the Moon.

Representation 4: 2D Diagram of Moon Orbit and Illumination as Seen from Space

At this stage the interactive whiteboard (IWB) display is changed to a 2D diagram with the Earth at the centre and two representations of the Moon phases; an inner circle showing the astronaut's view and an outer circle showing the view from Earth. She first established which circle represents the Earth, and Moon, and where the sunlight is coming from. She used a pointer to do this. She then began to show them how to fill this in on their sheets, which were duplicates of this image. Figure 7.2 shows the sheet (only partially correctly) filled in by a student.

Teacher: *So the moons in the inner circle are the ones the aliens saw.*
You will draw the dark and bright sides of all these moons.
… Doesn't this look really similar to what we just did?
… Sun light comes this way…and this is earth…and the moon moves in this way
… just draw according to what we just saw.

Ms Hong thus links the inner circle of the diagram to the alien view they noted from the role-play. These conventional drawings are a stripped down version showing the salient feature of the half-lit ball. The drawings link back to previous drawings. The particular affordances of this drawing, which is complex and represents two separate perspectives, lie in the abstraction of the shape sequence and its link to the sun-earth-moon position, in a transportable form that reifies what was experienced over time in the model, into a cartoon time sequence of frozen moments that allows the situation at different times to be reified and compared.

Representation 5: Student Completion of 2D Moon Phase Diagram

Ms Hong then asked students to fill in the outer circle moons from what they had observed. She linked the diagram now through recall of position numbers.

Teacher: *Now please draw the four moons on outer ring.*
These four moons can only be observed by humans from Earth.
What did the Moon look like when you observed from position 1?
How about position 2?

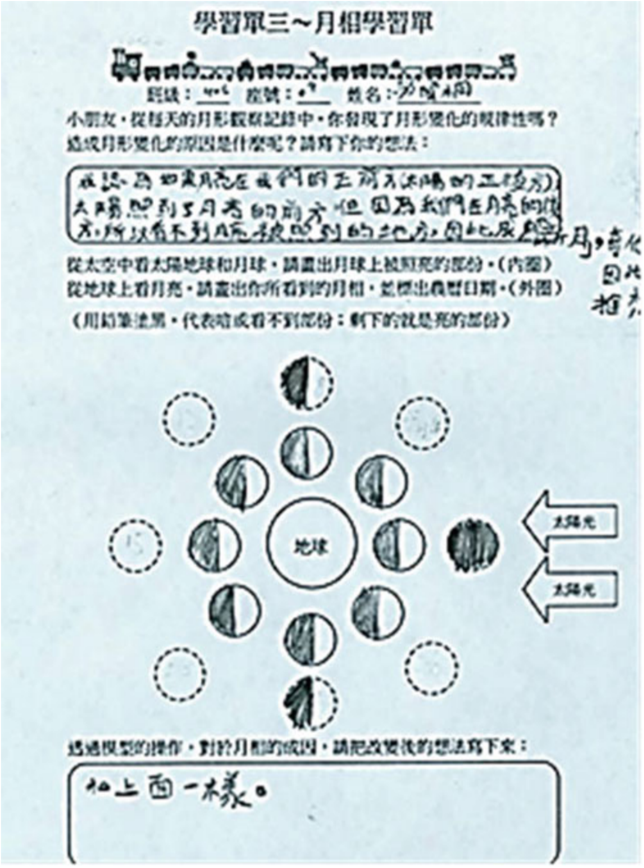

Fig. 7.2 The worksheet, partially filled in, showing the space and earth views of the moon phases simultaneously

The students were then asked to produce a version of the conventional moon phase diagram, which (1) abstracts their observations of the ball to the bare essential of the shape, (2) duplicates what the Moon looks like in the sky, and (3) links to the photograph sequence. This diagram is notorious for its complexity in simultaneously representing two perspectives but Ms Hong has carefully prepared students for this with her constant emphasis on the two perspectives and her separating of these two aspects of the drawing task. The diagram also links to a photograph version on a website the students were referred to.

Representation 6: Construction of a Written Explanation of the Cause of Moon Phases

Teacher: *Why do you think there are changes of moon phase?*
Why is the moon we see different every day? What is the cause?
Please write down the reasons that you learnt from today's experimental operation process!

This reduction to verbal text is often the end point of science lesson sequences. It demands a coordination of visuo-spatial representations that have been the subject of the lesson, into a reasoned narrative logic, and demands a formalising of the language around phase and sun-earth-moon relations.

Discussion of the Case

The features of Ms Hong's lesson that stand out are; (1) the way the sequence was designed to move from the central question about explaining the moon phases through a staged 3D embodied model, leading to 2D abstracted representations and finally a verbal re-description, (2) the way she foregrounded the salient features of each representation by focused questioning and gesture, and (3) the variety of devices she used to link the representations including the earthling/astronaut analogy to represent the shift in perspective needed to explain the phases, physical proximity of the different representations, and gesture and talk pointing out the features-in-common of the representations. These aspects of the lesson are represented in Fig. 7.3, showing the sequencing, the salient features and the linking moves made.

Case 2: Ms Grace's Sequence on Day and Night

Ms Grace is an experienced teacher of science who drew from a range of multimodal representations for inquiring into the cause of day and night (Hackling et al. 2013). In this one-lesson learning sequence from Western Australia Ms Grace introduced six major representational activities. These moved from teacher demonstration to small group role-plays that engaged the students in interpreting, refining and constructing representations of the phenomenon of night and day. Ms Grace used the core activities from the *Primary Connections* unit of work *Spinning in Space* but modified them to bring out what she saw were the key learning purposes.

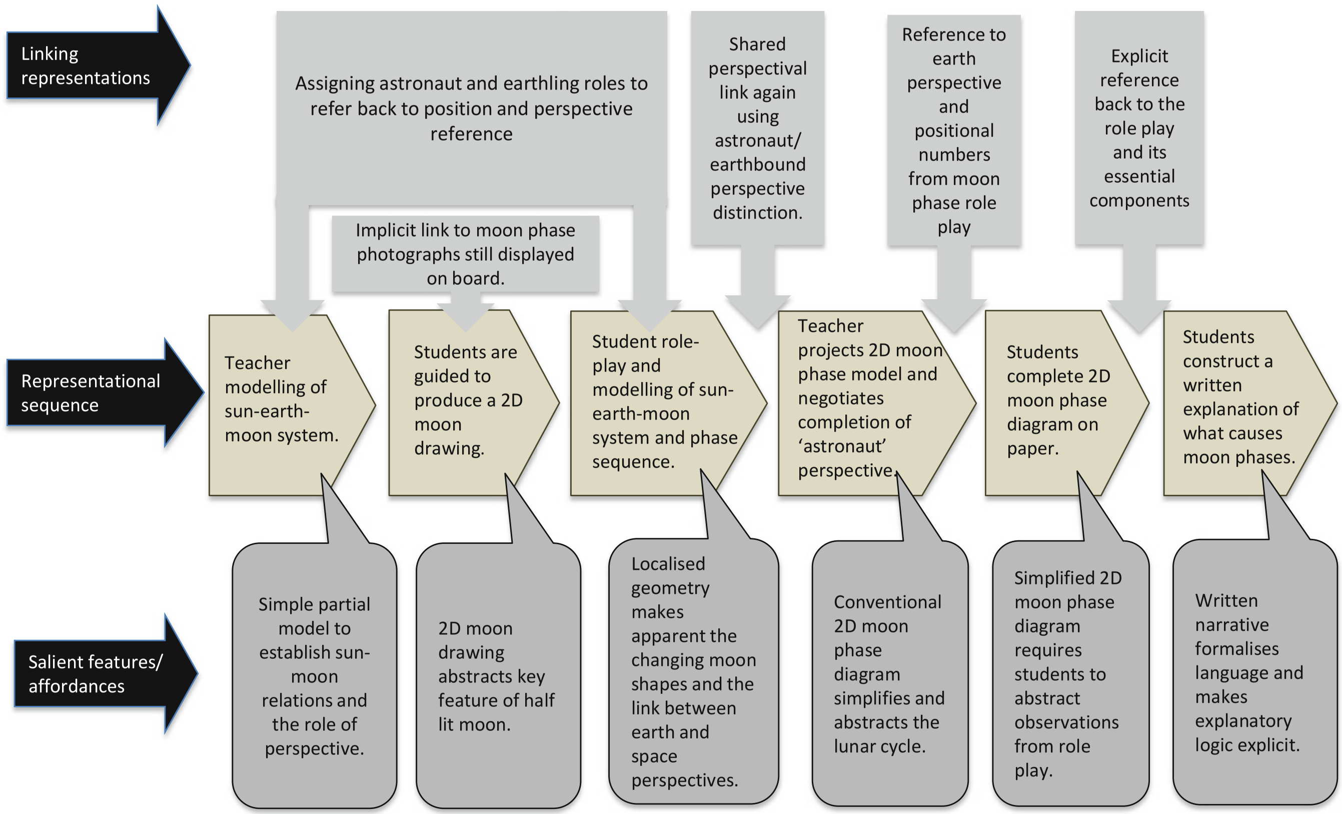

Fig. 7.3 The sequence of representations, their salient features, and linking moves used by Ms Hong

Unpacking the Modelling Lesson

The modelling lesson involved a sequence of representations involving model based reasoning and explanation. The substantive science conceptual content was the spinning of the Earth on its axis causing day and night. As with Ms Hong, the sequence of representations formed a coherent multimodal narrative. Ms Grace's questions were used to focus students' attention on the salient aspects of the multiple representations of the phenomena. Questioning, pointing, gesturing and explicit verbal interpretations/explanations were all key strategies she used to move from one representation to the next.

As an example of the linking strategies, we examine how she coordinated the transitions across four consecutive representations of day and night: (1) a 2D map of Australia with the Sun's movement superimposed, (2) a satellite image of the Earth spinning slowly, with half in brightness and half in darkness, (3) a role play with students spinning within a hoop to represent the Earth, and a central lamp to represent the Sun, and (4) an open-ended modelling task where students were charged with representing night and day using balls of various sizes.

Representation 1: A Role-Play Using a Lamp in the Centre of the Floor, of the Earth Orbiting and Spinning

Following a review of previous ideas involving light and shadow, Ms Grace posed the challenge: "How could we represent night and day in the classroom?" She first demonstrated a role-play of the movement of the Earth in relation to the Sun (represented by a lamp in the middle of the classroom), over a year but also rotating on its axis, as a rotating hoop with herself inside it. She asked: "What do you think the earth might do, and how might we represent it?" In the discussion she distinguished between what happens in a year, and in a day, emphasising the terms 'orbit' and 'spin'.

Representation 2: IWB Image of the Sun Moving Across a Map of Australia

She then displayed a representation on the interactive whiteboard (IWB) of a 2D map of Australia, on which the students marked the positions of Sydney and Perth (Fig. 7.4). She talked about the Sun appearing to move across the sky and referred to their experience of the Sun setting on the western horizon. On the map the Sun was initially positioned off the East coast and was then animated to move across the map to the West. "The Sun moves in that direction (gesturing). So this is morning" (pointing to its initial position on the right) "… and this is evening (pointing to the

Fig. 7.4 An IWB image of the Sun moving across the Australian map

left side). The Sun appears to move, but in actual fact we are moving". She thus clarified the language issue that reinforces the particular earth perspective of the Sun's relative movement. This served as an introduction to the next representation, of the Earth spinning in space.

Representation 3: Animated Satellite Image of the Earth Spinning in Space

Ms Grace then projected a satellite photograph of the Earth, with the light coming from the right with "this half of the Earth is still dark, this half of the Earth is light". The shadow line cuts through the centre of Australia. "So look at Australia. What can you tell me about Sydney? (pointing) … it is in daylight (acknowledging choral response) and Perth? (pointing) … It's still in the dark time". She then used questions to establish that "Sydney gets the sun first" and reinforced this with an animation where the Earth rotates. "The Sun would be here providing all the light on this side of the globe" (she used hand gestures to represent sunlight flowing from the right onto the globe (Fig. 7.5)).

In the sequence Ms Grace has moved from space, to earth, to space-centred representations, discussing explicitly the language associated with 'sun setting'. In each representation she used gesture and talk to position the Sun and the Earth, and Sydney and Melbourne.

Representation 4: Role-Play of Spinning Earth with Students Representing Sydney and Perth

Ms Grace then returned to the role-play using a hoop for the Earth, this time positioning four students inside the hoop looking outwards, asking them to represent the Earth spinning. She handed cards labelled 'Sydney' and 'Perth' to two students and organised them such that "Sydney sees daytime just a little bit before Perth does". The students 'spin' so that Sydney and Perth see daytime consecutively as they 'face

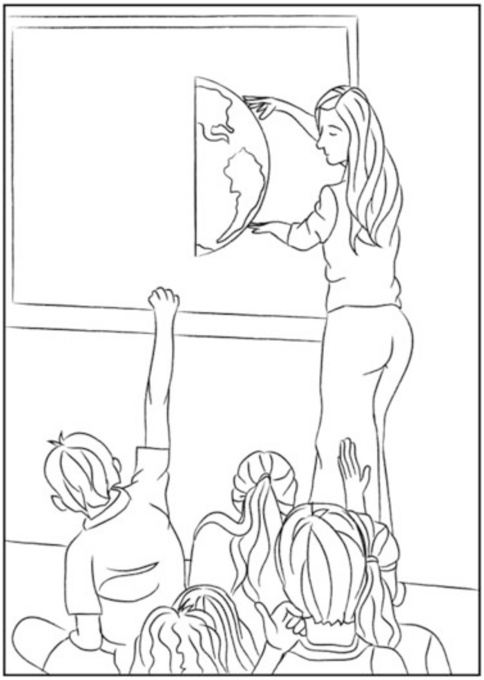

Fig. 7.5 Animation of the Earth spinning: "The Sun would be here providing all of the light on this side of the globe"

the Sun'. During this discussion she explicitly managed the movement, and pointed out students, who represent day and night, and Sydney and Perth (Fig. 7.6). In this way she again moved between space and earth-centred perspectives through talk and gesture. Students looking on experienced a space perspective, while students in the hoop, and by implication, students empathising with their experience supported by Ms Grace's talk, experienced an earth perspective. Sydney and Perth are again used to focus attention on what is experienced on the Earth, but interpreted from a space perspective.

Representation 5: Open Ended Modelling Task

Ms Grace then introduced an open-ended task in which groups of four students planned how they would use balls of different sizes, and torches, to "represent day and night". In their ensuing presentations the students gave very general representations of the Earth spinning (and orbiting) but she successively questioned them and re-voiced their responses to establish the link between light from the Sun, half the Earth lit up, and what is experienced from earth. For instance she interceded in an early group presentation in which a torch beam was trained on a small basketball (Fig. 7.7):

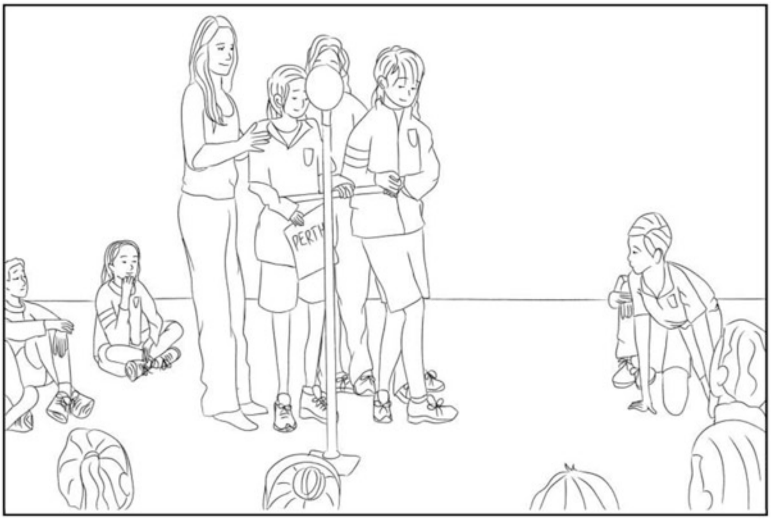

Fig. 7.6 Role-play of spinning earth – “Let’s spin so that Perth is in daytime”

Fig. 7.7 If I put my finger there and pretend I’m standing there; and you can spin the Earth

> *So if this half of the Earth (gesturing) is facing the Sun it is …? … Daytime (affirms choral response). So if I put my finger there (putting finger and holding it as ball is spun) and pretend I’m standing there … and you can spin the Earth … now my part of the Earth is at night and … keep spinning … and now where I live has become … ? Daytime (affirms choral response).*

Thus, she again established the link between the space perspective implied by the model and the Earth perspective as imagined by an observer at a particular point.

This was first established using the 'Sydney' and 'Perth' device, then these places were linked to the embodied representation of students within a spinning hoop, and now the perspective had been abstracted to a finger placed at a particular point.

The lesson ended with Ms Grace coordinating a physical globe model, and an IWB representation of the model to sharpen the language around the Earth spinning on its axis, and to distinguish between the Earth's 'orbit' and 'spin'.

In this lesson the representational sequence (see Fig. 7.8) was used to establish relations between the complex visual, spatial and embodied relations needed to understand the day-night phenomenon. We argue that an understanding of day and night consists of the capacity to coordinate these representations as the discursive tools through which problems of day and night and time are solved. Further, it is clear from the analysis that the representations are actively talked and gestured into existence as students' attention is drawn to the salient features of each representation, and the way they are linked visually and spatially. Finally, this analysis provides evidence of the single-mindedness with which Ms Grace has planned for and promoted this movement between the space and earth perspectives, which is at the core of understanding astronomical phenomena.

Case 3: Ms Petersen's Sequence on Modelling Moon Phases

This sequence is somewhat different in structure to the other two. The modelling sequence analysed below follows an exercise over the first two lessons involving children sorting the moon phase shapes, followed by a role play leading to the phase sequence being arranged on the board, and the terminology of waxing and waning of the Moon established. The third lesson involved an introduction of a tellurium model (with the Sun, Earth and Moon mounted on a set of rotating arms) and open discussion concerning what could be learnt from this about the motions of the Sun, Earth and Moon. In lessons four, five and six students: (1) constructed their own small models to demonstrate moon phases, (2) further explored these ideas through gathering once more around the tellurium, and (3) discussing a worksheet with a 2D representation of the Moon's phases linked to its orbital positions. The sequence involved more extended discussion, over four lessons, around students' exploration of the models than the previous two cases.

Representation 1: Introducing the Tellurium Model

Following establishment of the moon phase sequence, and an extended exploration of students' ideas about sun-earth-moon relations, the class was seated on the floor around a tellurium model in which the orbit of the Moon around the Earth, and of the Earth around the Sun, became apparent (Fig. 7.9).

The teacher established through questioning the orbital relations between the three bodies, when a child asked: "Why did they make the Sun [in the tellurium] so

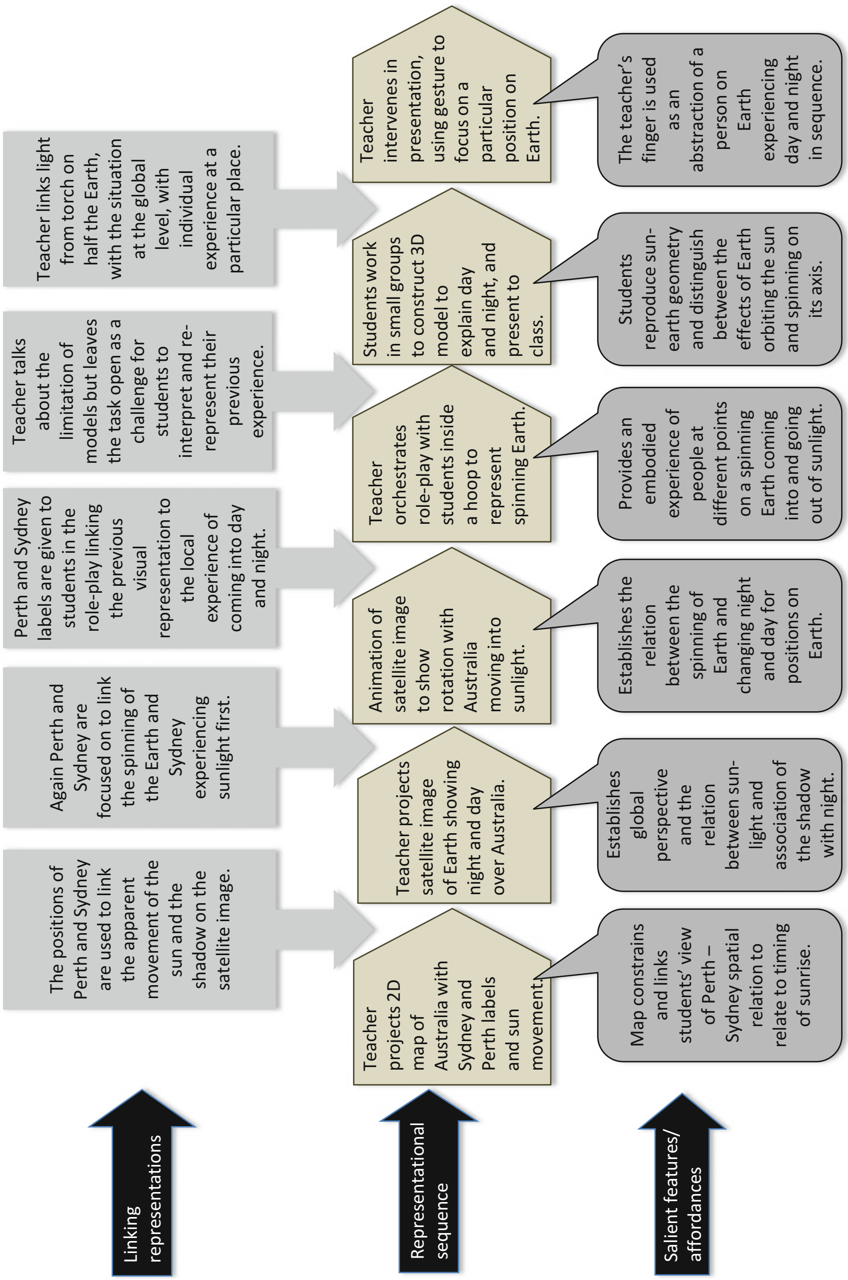

Fig. 7.8 The sequence of representations, their salient features, and linking moves used by Ms Grace

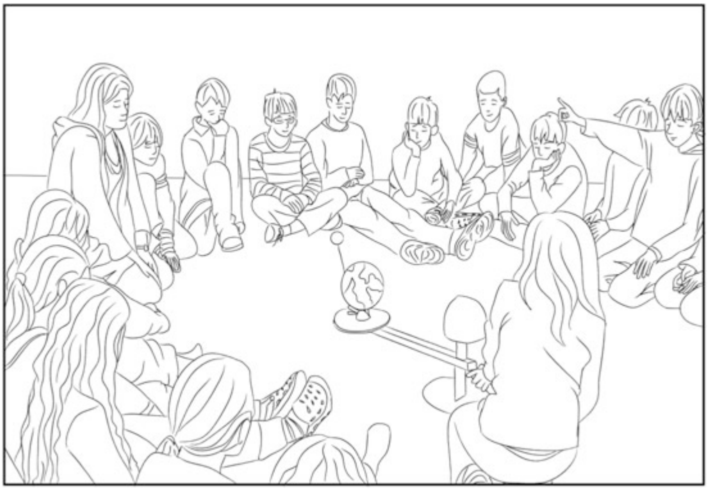

Fig. 7.9 The children sit in a circle to discuss the Tellurium model and its implications

small?" This led to an open discussion about the relative size of the Sun and the Earth, and Ms Petersen gave this question back to the children.

The discussion leads to a number of insights concerning the nature of models:

Student Do: *Because one can't make the Sun so big in this case.*
Teacher: *Why not?*
Student Do: *Because … because it would be too heavy or too large.*
Teacher: *Mmhhh, Ni?*
Student Ni: *Because otherwise the whole thing would fall over, and because presumably it would smash down through the floor all the way down.*
Teacher: *That heavy? Ok! Da?*
Student Da: *Well, if one, if one made the Sun as big as the Earth in that case one would simply make the Earth smaller but then one would have to make the Moon even smaller and … then the Moon would be so tiny that one could hardly see it and … then that doesn't help.*
Teacher: *Ja?*
Student Ja: *But my father also told me that the Moon is six times smaller than the Earth.*

At which point Ms Petersen discussed the nature of models:

Well this is always the great difficulty; you will often be looking at so-called models in school which are used to somehow better explain something to you. But the problem with models is always: It is not reality! One just can't build it so that it looks exactly like in reality but one can use it to explain something.

Following this, Ms Petersen led the children in a discussion, through questioning, of how the model can be used to explain the different moon phases. She asked children to nominate, using the model, at what positions the different phases, new, quarter, and full moon, would occur. During this discussion, gesture and positioning of the model were used to explicate the salient features of the sun-earth-moon spatial relations, with the children being invited to take an active role.

Teacher: *What do you think, how would you see a crescent?*
Student: *If the Moon turned this way.*
Teacher: *Well, position it!*
Student: *Well, if the Moon turns this way, so that it beams its rays here somehow.*
Teacher: *The way the Moon is positioned right now, what do you think what phase of the Moon would you see? You are there on the Earth, Sami?*

The children got caught up with the notion of eclipses, which is inevitable given the scale of the tellurium and that the Earth, Moon and Sun are shown in the same plane. Ms Petersen explained that these are special cases and illustrated how the Moon can be positioned vertically to illustrate how monthly eclipses are avoided.

Teacher: *I would like to tell you a secret, the fact that the Moon can be lowered and raised on a telescope bar is something particular to this model … one can (move it) here like that. The Moon does not rise and set, rather it turns, here. This is the movement of the Moon that is of importance to us.*

She concluded by asking children to nominate the positions for the major phases of the Moon, again using the model and gesture to support their claims. There was no closure on the discussion.

Representation 2: Children's Models of the Moon Phases

Groups of children were supplied with different size polystyrene balls, torches, and wires and wooden skewers with the task of constructing a model: "and think about how one can see the phases of the moon with the model". The children tested their models in a darkened room (Fig. 7.10). Some groups constructed drawings also, to support their model thus transferring the 3D-model into a 2D-representation. Ms

Fig. 7.10 A child using his finger to pinpoint the illuminated part of the Moon as seen from earth, in his self-made 3D-model

Petersen discussed each model in turn as it was presented, intervening strongly, as needed, for instance by asking children to position themselves looking from the Earth, as she challenged them to establish the positions that represent the different moon phases as seen from earth.

Student: *This is the full moon! (Sudden realisation in looking from the direction of earth)*
Teacher: *Now you have a full moon, right?*
Students: *Yes!*
Teacher: *Well, then how are sun, earth and moon standing? Is the Moon between the Sun and the Earth? Or next to them?*

There was general agreement that the Sun is behind the Earth opposite to the Moon.

Teacher: *So, ok … Take care that you… Can you see how the Moon is illuminated here? (Ss: Yes!) Now if one was a little man on the Earth, one would see the Moon this way (positioning the eye to look from earth to moon). Ok. So what does a new moon look like?*
Student: *That's a question I also ask myself. S2: Huh?*
Teacher: *That's a question you also ask yourself? (S: Mhm) Well, let's see whether the group can give you an answer.*

In these group sequences Ms Petersen uses gesture and body position explicitly to establish the look of the moon phases from an earth perspective. The models can only be made sense of if one looks across to the illuminated moon from behind the Earth.

Representation 3: Revisiting the Tellurium

The tellurium in the following lesson was used to consolidate the learning from the group modelling lesson. This time Ms Petersen put a small flag on the position of Berlin and led a discussion where she challenged children to position the model moon first for the new moon then for other phases. The embodied understandings based on looking at the Moon from the position of the flag were much more explicitly dealt with in this lesson, and children were encouraged to move round and report on what they saw, viewed from earth, for the different moon positions.

Teacher: *So, Ma.., look, you are here, in Berlin. Go stand there in Berlin and look at the moon. How do you see it illuminated right now?*
Student Ma: *Noo!*
Teacher: *So, what kind of a moon is it?*
Student Ma: *Mhhh [.] New moon?*

Figure 7.11 shows the situation of children gathered round the tellurium, and Ms Petersen pointing to what should be focused on, with the lighting of the full moon that a child has positioned.

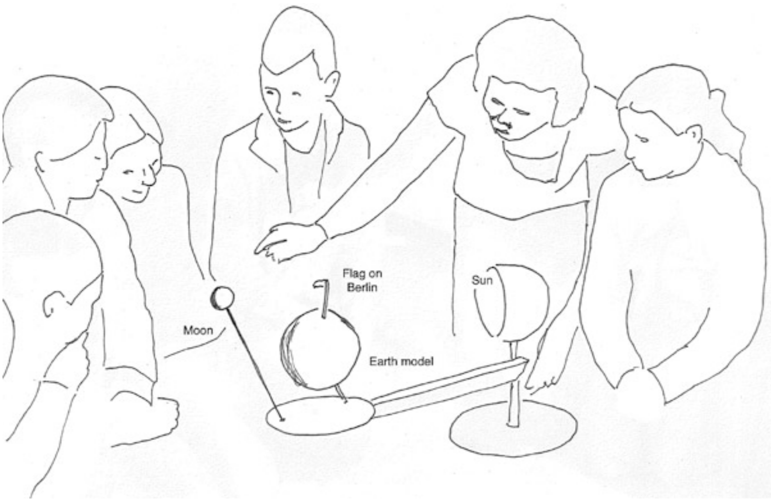

Fig. 7.11 Ms Petersen focusing attention of the lighting situation for a full moon

Representation 4: 2D Moon Orbit Diagram

In subsequent lessons these observations were linked to the different moon phases and dates, involving drawing, and the coordination now of shapes, patterns, dates and terminology. She introduced a worksheet that contained a representation of the Moon in orbit in different phase positions, with the figure of an eye representing the view from earth (Fig. 7.12), and explanatory text.

As with her emphasis on an embodied experience of the view from earth in the student models, and the flag on Berlin, she emphasised in the discussion the view from earth.

Teacher: *You see the eye. What is the eye meant to be, Be..?*
Student Be: Eh, when one sees it.
Teacher: *Yes, and where, who sees himself where and what, Pa..?*
Student Pa: *The Earth.*
Teacher: *That's us on the Earth, right? We are looking at the Moon from the Earth.*

Ms Petersen then encouraged commentary on this worksheet, and had children articulate narrative explanations of what is happening to cause the moon phase at different points in the orbit:

Student Da: *The Sun always stays in the same place and then when the Moon is between the Sun and the Earth then the Sun doesn't shine around the whole moon, but rather only where we can't see it from the Earth. So that's why we don't see it at all then.*

As with Ms Hong and Ms Grace, Ms Petersen strongly signalled coordination of these last three representations through a particular device: in her case involving an embodied emphasis on the view from earth, first through the experience of seeing

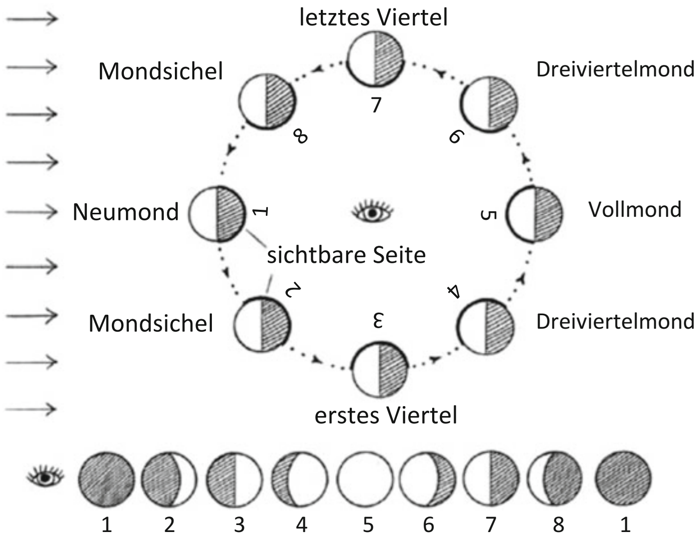

Fig. 7.12 2D representation linking phases (new moon, crescent, first quarter, three quarter moon etc.) as seen from earth with points in the Moon's orbit (Reproduced from "Sichtbare Seite": "Visible side" (http://www.sonnentaler.net/aktivitaeten/astronomie/himmel-erde/mondfinsternis/, © www.sonnentaler.net, Freie Universität Berlin 2013)

the Moon from an earth perspective in the student models, then by looking across the flag on the tellurium, and finally the eye in the 2D orbital diagram.

Similar to Ms Hong, she focused on coordinating earth and space views, and moved across 3D models, embodied experience, a 2D representation that reified the temporal dimension spatially and allowed coordination of phases with orbital position and time, and a final challenge for children to construct narrative explanatory accounts of the phenomenon.

The sequence of lessons involving modelling is shown in Fig. 7.13. The sequence, however, differs from the other two in a number of ways. First, the coordination is across similar models (the tellurium and student group models) rather than mixing modalities. More so than for Ms Hong, the focus here was on developing an embodied interpretation of the 3D model through gesture and body positioning, and the use of a flag to signal the position from which one should look. In the subsequent lessons explicit attention was given to linking the moon phase representations, the dates, and the language (new, full, quarter moon, waxing, waning). The 2D photographs of the different moon phases remained on the classroom wall throughout this process.

Second, each of the four representations took a full lesson rather than the sequence taking place over one lesson. The pedagogy was slower than for the other two teachers, and involved more focused exploratory discussion where students were given considerable space and time to express their ideas, hypothesise and make claims. Third, there was more emphasis on extended group work than with the other teachers. The modelling challenge was more scaffolded and more extended

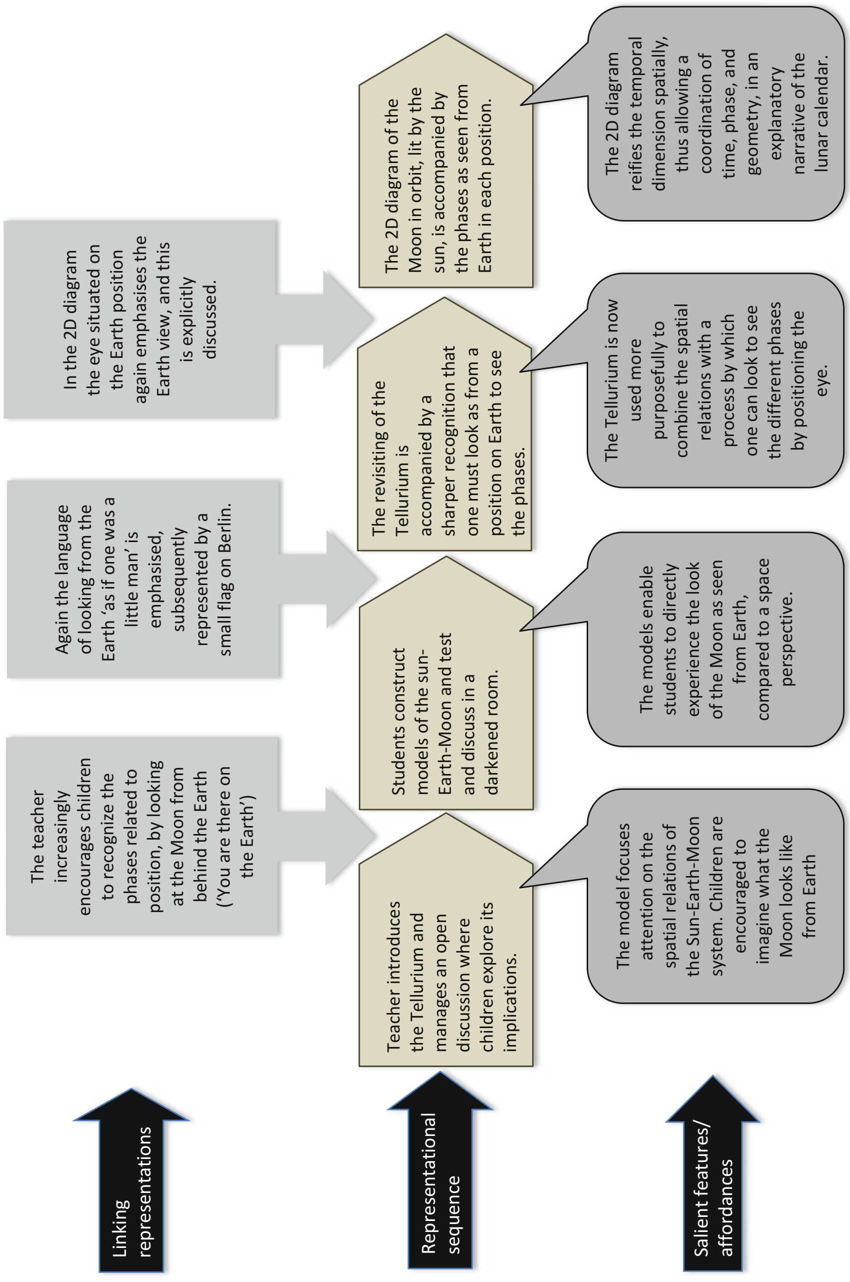

Fig. 7.13 Ms Petersen's sequence of modelling activities

than was the case for Ms Grace, but like Ms Grace, Ms Petersen actively used the group work to emphasise the salient features of the representation, similarly focusing on the place in the model that would provide an earth perspective. Fourth, Ms Petersen is the only one of these three teachers who explicitly discussed the nature of models and their relation to reality, and to explanatory function.

Discussion

The analysis of these three astronomy sequences provides insight into a number of aspects of teaching, reasoning and learning in science, namely: the role of representation in reasoning and learning; the nature of quality teacher practice in establishing meaning through representational re-description and coordination; and, the cultural factors that shape the way teachers introduce and coordinate representations. We will discuss these in turn.

The Role of Representation in Reasoning and Learning in Science

Astronomy is a challenging topic for primary years, since to understand the interrelations of the Sun, Earth, Moon and stars requires students to de-centre and take the position of an observer outside the system, which in reality is impossible for children and others except for astronauts. Thus, perhaps more so than most topics, understanding astronomy involves the use and coordination of abstracted visuo-spatial models to problem solve and explain astronomical phenomena. Nevertheless the principles of representation as core to knowledge generation and learning in science hold for all scientific topics (Lehrer and Schauble 2006; Lemke 2004; Tytler et al. 2013b), so we argue that the analysis is relevant for the teaching and learning of science generally. There are a number of findings concerning representation, reasoning and learning, therefore, that are of broader significance than for astronomy, concerning:

- The central role of representations in establishing meaning and supporting reasoning in science. It is clear in all three cases that astronomical relations can only be understood through these multiple, multimodal representations, such that reasoning to solve problems and generate explanations of moon phases, or night and day, can only occur through mastering these various representations, including gesture and embodied representations, and natural language, and their coordination (Kozma and Russell 2005). These representations and their coordinated use can be understood as the discursive tools constituting a scientific disciplinary literacy into which these students are being inducted (Moje 2007). In the case of astronomy the key problem being addressed is the need to be able to shift between space and earth perspectives.

- The constructed nature of representations. In each case, the models introduced by the teachers did not 'speak for themselves' but rather needed to be generated as a communally understood representation through talk and gesture. Thus, Ms Hong's modelling of the Moon as a ball lit by a light involved not only the physical apparatus but also the students themselves occupying a space and an earth perspective, established through gesture and talk.
- The partial nature of each representation, and the particular affordances of each in productively constraining students attention (Prain and Tytler 2012), such that reasoning to predict or explain astronomical phenomena inevitably involves the coordination of one or more modes.
- The modal and dimensional transformations that are involved in representational re-descriptions mirror the process of knowledge generation in science (Gooding 2005). Thus Ms Hong moves from 2D photographic representations to a 3D model of the sun-moon system to a 4D modelling involving the Moon's orbit over time, and back to a 2D representation of the Moon's appearance. In this context it is noteworthy that both the German and Taiwanese teachers had organised for the children to observe the Moon in the evenings and note its appearance over time and report their observations in the classroom, thus building a bridge between the 2D-pictures and the 3D-model in the classroom and observations of patterns involving the real Moon in the sky.

Quality Practice in Representational Work

These teachers all seemed to be very deliberate in planning representational work, and were articulate in identifying the key challenge as the need to provide discursive tools enabling students to shift between space and earth centred perspectives in their reasoning. Analysis of the three sequences allows us to produce some generalisations concerning quality practice in representational use. We can also identify features of this practice that differ for the three teachers, which represent choices concerning approaches to supporting student reasoning and learning through representation.

- A key finding from the analysis concerns the strategies teachers use to construct and coordinate representational work. The teachers, particularly Ms Hong and Ms Grace, were very deliberate in the way they planned sequences of representations that shifted in mode and dimensionality, and used considered devices to link these. A key device used by Ms Hong and Ms Grace in linking representations were the use of narrative analogy that emphasised features in common across the representations of earth and space perspectives. Thus Ms Hong referred consistently and explicitly to 'earthlings' and 'astronauts' as a common theme across representations, and Ms Grace referred to the positions and sunrise times of Sydney and Perth across multiple representations to ground these in a common context. Each teacher explicitly referred back and forth to the different

representations, and in a number of cases had multiple representations on view in the classroom at the same time, such as the constant presence of the moon phase sequence in Ms Hong's class as well as in the class of Ms Petersen. The other major strategy included, in all cases, the pointing out of the salient features of the representation that needed to be focused on ('For which of you in the hoop is it morning now?', 'How much of the Moon can you see lit now? … you don't all see the same?') through talk and gesture. Ms Petersen increasingly challenged students to position themselves in relation to the tellurium models to look across the Earth to the Moon image, to experience the phases directly. She achieved the Earth and space-centred perspectival shift using embodied experience, and talk.
- Allied with these strategies was the use of questioning to monitor students' understanding of the way the representations worked as reasoning tools. Thus, students were asked to identify key features of a representation and link to previous representations, or link aspects of a representation to predict how it related to the phenomenon, such as the particular moon phase, or the time at a particular point on earth relating to a role-play or part of a physical model.

The three teachers differed in significant ways, however, in the style of questioning they used, and the degree of explicit scaffolding they provided for student reasoning. There was also a difference in the openness of the representational tasks.

- Ms Hong's questioning was predominantly framed to elicit short responses that did not require explicit voicing of reasoning by way of extended speculation or justification. Questioning was used mainly to have students interpret the meaning of the representation ("Which of you is the astronaut and which is the earthling?") and to achieve a group agreement on what was being presented. Students were certainly being asked to reason, but tightly constrained within the frame of the canonical representation that was offered. Ms Grace's questioning sequences tended to be more open and inviting of extended responses, although also strongly scaffolded. Ms Petersen was more open in her questioning than the other two teachers, inviting students to predict and interpret the tellurium model and allowing space for students to speculate and justify their responses. Thus, student talk in the German class was more extended and more explicitly displayed reasoning, with claims and justifications encouraged and more interactive sequences with multiple students responding to each other's ideas.
- In terms of the openness of representational tasks, again there is a spectrum from the Taiwanese through the Australian to the German sequence. Ms Hong's tasks were quite demanding, going beyond the set curriculum, but they were strongly scripted and designed to introduce students to canonical representations that can be found in textbooks. Ms Grace's early tasks were also strongly scripted and canonical, but the modelling task with balls was quite open. In this she monitored progress by moving from group to group questioning their model construction and interpretations, and probed carefully and intervened during the class presentations. In Ms Petersen's sequence the class sat around the tellurium, a classic representation of sun-earth-moon relations, but engaged in open speculation about what it showed about moon phases. At one point the discussion diverged to

a consideration of the nature of models, triggered by a student's question. This was the greatest extent of student-initiated activity in these sequences, and the only example of explicit discussion of the nature of models. Such explicit discussion is a key feature of the representation construction inquiry approach recommended by Tytler et al. (2013b). Again, Ms Petersen's task requiring students to construct their own models and present them to the class was quite open.

Thus, there is a variety of approaches to setting representational tasks, and to monitoring in the lessons, including closed questioning and observation to monitor student interpretations, to more open questioning and constructive tasks to monitor students' capability to use the representation in prediction and explanation. There was a different emphasis in the three classes concerning the extent of student construction and interaction, compared to active confirmation and interpretation. In Chi's (2009) terms, in Ms Hong's sequence students were active, and at times constructive in re-representing their 2D diagrams and narratives, but at no point was there open discussion in which they shared and justified their ideas. In Ms Grace's sequence students were active for most of the lesson, and constructive and interactive in creating and presenting their models. However, in most cases Ms Grace needed to intervene to sharpen the interpretation of their model she was looking for, and no group reached a point where they were able to confidently explain and justify their models. In Ms Petersen's sequence students were active during the discussions and constructive/interactive with their model creation and presentation. This was a more constrained task given the students had been exposed to the tellurium, and the particular affordance which Ms Petersen emphasised lay in the visual exposure, in the darkened room, to the moon phases seen from an earth perspective. In the final tellurium lesson, students were encouraged to report and justify which positions of the moon corresponded with different phases, making this an interactive task.

Student Reasoning and Learning

Corresponding to the degree of openness of the questions asked by the teacher, student responses varied in the explicitness with which they demonstrated reasoning. We take reasoning; whether it be deductive, inductive, abductive (generating a probable explanation on the basis of evidence), or model based; to involve the use of evidence to generate new claims, and provide justification (see Tytler et al. 2013a). This explicitly occurred in the model construction tasks in Ms Grace's and Ms Petersen's sequences, and in the speculative discussions around the tellurium model in Ms Petersen's class. Ms Petersen actively encouraged students to speculate and justify, and we can see this in the discursive moves analysis of the previous chapter with the length of student talk, and the incidence of claims and justifications. However, clearly this does not mean that reasoning was not supported, nor occurred, in other cases. When Ms Hong asks, for instance, "Is it possible for you to see when the Sun shines on the Moon if you are viewing from the Earth?" students need to reason in order to answer this question, but no justification is asked for. Reasoning, and learning, seems to be judged by whether reasonable responses are given to constrained questions. There is a continuum therefore, in the tasks and discussions across these three sequences, concerning the degree of support and encouragement of reasoning expressed through extended talk in response to open questions, as opposed to expressed through voicing of short but correct responses to tightly constrained questions.

The Role of Context and Culture

There are commonalities in these sequences that reflect competent teachers' approach to representational work that cuts across countries. There are, however, substantial differences in the three sequences that partly reflect individual teacher styles and approaches, but substantially reflect cultural practices and curriculum framing specific to the three countries. While the three teachers cannot be taken to be formally representative of their countries' education systems, they are broadly representative of what is considered good practice in the country, and on-going discussion and joint analyses within the EQUALPRIME team has identified particular traditions and circumstances within each country that are reflected in the sequences.

First, the differences in the extent to which ideas are introduced and constrained by the teacher, as distinct from emphasis being given to students generating ideas, reflect strong cultural traditions. In Taiwan there is a tradition of keeping the pace moving in classes, to efficiently introduce and support student learning of scientific ideas. This tradition is supported by a tightly prescribed curriculum and textbooks and other resources that are state-mandated, and quite detailed. Further, there is an overt and competitive assessment regime. When Ms Hong expressed a strong belief in the role of the teacher to strongly structure students' experience "to save students time when they try to find out the answers by themselves", she is consistent with the valuing in Taiwanese classrooms of strongly guided and efficient curriculum coverage. This argument for representational shortcuts to abstracted knowledge is, of course, a strong tradition in science teaching in countries other than Taiwan, and one to which Ms Grace to an extent also subscribed.

However, the Australian curriculum is not so strongly prescribed as in Taiwan, and there is not a strong testing tradition, so that teachers have more latitude in framing sequences. There are no mandated resources, but nevertheless Ms Grace drew heavily on the *Primary Connections* materials, which provided a varied sequence of astronomy representations. In Australia there is a strong tradition of group exploratory tasks, reflected in Ms Grace's open modelling task. There is also a more general subscription to the value of extended student talk, although this did not occur to a great extent in this sequence.

In Ms Petersen's sequence however the German tradition of valuing student communication, and students openly exploring ideas, was very evident. This approach refers to the German ideal of 'Bildung' which aims at an autonomous person who is very well skilled in using sophisticated language for being able to participate in public life. Ms Petersen worked to encourage students to speculate, reason, and respond to others' input. The lack of closure in linking the initial sequence of moon phase ordering, the work with the tellurium model, and the production of self-made models by the children may reflect the lack of specificity of curriculum prescription for this topic, and the fact that Ms Petersen had to produce her own resources rather than draw on a structured sequence of representation.

Conclusion

Thus, in these sequences we can discern general, powerful principles that cut across countries, concerning the introduction and coordination of multimodal representations to support student reasoning and learning in science. We can identify, however, significant differences in the way these three teachers structured their questioning to support student learning, and differences in the openness of representational tasks. Finally, we have related these differences to the particular cultural and system contexts in which these teachers operate. We would thus argue that the study provides powerful insights into (1) fundamental principles of quality teaching through representations, (2) choices that are available to teachers in enacting these principles, and (3) the particular cultural traditions and presumptions that underpin these choices. We argue therefore that the analysis should provide useful lessons for the education of teachers of science in all countries.

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