Mark W. Hackling · Jörg Ramseger
Hsiao-Lan Sharon Chen *Editors*

Quality Teaching in Primary Science Education

Cross-cultural Perspectives

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EQUALPRIME: A Foreword: In Celebration of the Cross-Country Researcher

A foreword is not an introduction. An introduction has certain obligatory constraints regarding what must be said. A foreword has almost none. You can be forward in a foreword – you can push and peer and project and speculate. Not an opportunity to be missed. I thank the editors and the wonderful EQUALPRIME team for this opportunity.

The education community has a need for new approaches to research. Student mobility and global communication pose challenges for existing insularities of curriculum, of pedagogy and of research methodology. We need studies with breadth of vision. We need research with the capacity to destabilise assumptions. We need to compare; but, more importantly, we need to connect. We need research that connects the global to the local, the international to the school down the road and the teacher in Taipei to the teachers in Berlin and Melbourne. Connection is the key, but how to connect? The EQUALPRIME project succeeds in not only comparing the practices of teachers in Taiwan, Germany and Australia but in connecting those practices.

The various authors of the chapters in this book describe the EQUALPRIME project as cross-cultural and cross-country. As a metaphor for international comparative research, 'cross-country' captures some of the challenges of unpredictable, uneven terrain, of navigational difficulties and of changes in landscape and in local community. The cross-country researcher, like the cross-country runner, needs to be fit, well balanced, sure-footed, navigationally adept and tireless.

In this context, 'well balanced' encompasses both parity of voice and a willingness to engage in self-critical reflection; 'sure-footed' researchers adapt their methods to the various settings in which they operate; and, theoretically adroit researchers navigate their way through the plains of tradition, forests of orthodoxy, the jungles of contemporary inventiveness and the deceptive marshlands of popularism, charting a path from one vantage point to another, each offering a different perspective on the terrain traversed and yet to be traversed. In a community where 'fit' is synonymous with expertise and 'tireless' the analogue of rigour, the cross-country researcher reports their insights as a series of exotic postcards from abroad. In this book, these postcards take the form of multi-faceted case studies that juxtapose images from culturally differentiated classroom settings.

As will be clear from the chapters of this book, the choice of Australia, Germany and Taiwan provides a happy juxtaposition of primary school contexts in which science is very differently positioned. The different strengths of generalist versus specialist teachers in primary schools provide one point of comparison. The problematics of translating curricular vision into classroom practice can be seen in the uncertain and uneven classroom realisation of the advocacy of inquiry-based learning and science literacy.

The EQUALPRIME project offers a detailed examination of science pedagogy as it is lived in selected primary classrooms in Taiwan, Germany and Australia. Science curricula have become more aspirational, prioritising scientific reasoning and the associated practices and discursive forms employed by the science community. The capability of primary school teachers to realise this prioritisation in their classrooms is of major importance internationally. The EQUALPRIME project contributes a much-needed fine-grained portrayal of the practices of primary science classrooms in very different cultural settings, complementing the survey-style approach and junior secondary school focus of the 1999 TIMSS Video Study (Roth et al. 2006).

> International comparative research offers us more than insights into the novel, interesting and adaptable practices employed in other school systems. It also offers us insights into the strange, invisible, and unquestioned routines and rituals of our own school system and our own classrooms. (Clarke 2006, p. v)

International comparative research offers distinct and characteristic insights – expanding our conception of what's possible and contesting our assumptions about what's essential. Challenged by the aspirations of the contemporary science curriculum, good teachers strive to translate curricular goals into classroom practice and student learning. Their efforts are shaped by the pedagogical traditions of the school system and the culture within which they practice their craft.

One of the measures of the effectiveness of an international research collaboration is the number of co-authorships arising from cross-cultural partnerships within the research team. By this measure, the EQUALPRIME team is remarkably successful. Almost every chapter of this book is a collaborative effort, combining the voices of at least two (and frequently all three) of the participating country teams. The chapters themselves address issues of contemporary relevance and theoretical significance: embodiment, discursive moves, the social unit of learning and instruction, inquiry and reasoning through representations. Through all of these, the EQUALPRIME team manages to connect the multiple cultural perspectives that characterise this research study. The 'meta-reflection' chapters offer a different form of connection, linking cultural and theoretical perspectives on reasoning, quality teaching and video-based research methodologies. The final two chapters offer connective links to implications for practice in teacher education and in cross-cultural comparative research into teaching and learning. These multiple and extensive connections constitute one of the book's most significant accomplishments.

The EQUALPRIME team also report, with engaging frankness, the difficulties that accompany intercultural comparative research. These concerns warrant consideration by all those undertaking intercultural comparative studies, whatever the methodology employed. EQUALPRIME not only draws attention to concerns such as common coding frameworks and the need for thick detail to support researchers' inferences about teacher support or forms of scientific reasoning but makes clear the dangers of research studies where superficial, low inference coding conceals essential interpretive and explanatory detail. In a study that appropriates some aspects of ethnographic technique and the associated methodological baggage, the detailed discussion makes visible both the pragmatism essential to cross-cultural research and the nature of rigour. Questions of comparison are dealt with collaboratively and with a pleasing parity of voice from among those compared and comparing (Stengers 2011).

The EQUALPRIME project, as reported in this book, provides an important empirical base that must be considered by any system seeking to promote sophisticated science learning and instructional practices in primary school classrooms. By exploring the classroom realisation of aspirational science pedagogies, the EQUALPRIME project also speaks to those involved in teacher education and to teachers. I commend this book to the reader. It offers important insights, together with a model of effective, collegial, collaborative intercultural research. It will help us to move forward in important ways.

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We would also like to thank the colleagues who operated video cameras in the classrooms and enabled the team to capture such rich data; Barbara Sherriff who assisted with collating, editing and formatting material for the book; and Aufa Moosa who created many of the line drawings for the book.

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Contents

List of Figures

List of Tables

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Part I
Introduction to the Research Project

Part I comprises two chapters which provide: an overview of the EQUALPRIME project, how it was developed and its research design; and, an analysis of the social, cultural and contextual factors that frame primary science teaching in Australia, Germany and Taiwan.

Chapter 1
An Overview of the EQUALPRIME Project, Its History and Research Design

Jörg Ramseger and Gisela Romain

The Project's History

EQUALPRIME is an acronym for an international educational research project with the full title *Exploring quality primary education in different cultures: A cross-national study of teaching and learning in primary science classrooms*.

EQUALPRIME started in 2009 at a symposium on *Research and Evaluation for Quality Education* organised by Professor Hsiao-Lan Sharon Chen, the former director of the Center for Educational Research and Evaluation at the National Taiwan Normal University in Taipei. This was a joint symposium involving Deakin University in Australia. The National Taiwan Normal University is twinned to the Freie Universität Berlin as well as to Deakin University in Melbourne, which was how Professor Russell Tytler from Deakin and Professor Jörg Ramseger from Freie Universität came to meet at this conference.

Sharon Chen, Russell Tytler and Jörg Ramseger then explored the possibility of starting a tri-national research project on science education in the primary years, as science education seemed to be of national interest in all the three countries and the conditions for a collaborative project seemed to be favourable. Russell Tytler suggested that Professor Mark Hackling from Edith Cowan University in Perth, Western Australia, a well-known expert in primary science education, be invited to join the team in the following meeting in Berlin 2010. Professor Chen enlisted the support of Professor Chao-Ti Hsiung from the National Taipei University of Education, the 'Grande Dame' of science education in Taiwan. The first tentative agreements for a joint project design were jotted down on a paper table cloth at the conference hotel in Taipei.

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The Principal Investigators could all count on the support of their own teams of competent researchers at their respective home universities. Over the years the following persons have been part of these teams: Khadeeja Ibrahim-Didi, Karen Murcia and Barbara Sherriff (Edith Cowan University); George Aranda, Gail Chittleborough and Peter Hubber (Deakin University); Ines Freitag-Amtmann, Johanna Hochstetter, Gisela Romain, Anika Sulzer and Matthea Wagener (Freie Universität Berlin); Hsiao-Yuh Ku (National Taiwan Normal University); and Pei-Tseng Jenny Hsieh (Oxford University).

The initial phase of the project was generously funded by the National Science Council of Taiwan and the Centre for International Cooperation of the Freie Universität Berlin. Later on the Australian Research Council provided a 4-years research grant (ARC Project ID: DP110101500). Additional funds available to the different research teams were also used for the project.

The Principal Investigators, often accompanied by further members of their teams, met twice a year at major conferences. In some cases conferences were also organised by the EQUALPRIME teams themselves. The goal of the first meetings was to agree on common research procedures. These were documented in a voluminous paper entitled *Shared repertoire of values, goals, methods, and procedures*. This shared repertoire was developed and continually refined during the meetings of the team members over the course of several meetings. The fourth and final version of the shared repertoire included theoretical positions, aims of the study, details concerning sampling, data collection and protocols for data sharing and analysis, publication of research results and ethical concerns.

The shared repertoire proved very valuable for the research process. Given the diversity of approaches, research interests and local conditions of teaching and learning as well as the vast distances between the research locations; this document functioned as a guideline for all phases of the research process. While the shared repertoire included detailed descriptions of procedures to be followed by all partners, for example concerning data collection, it also left room for variation to allow for adaptations to local conditions. Coming to an agreement over the shared repertoire resulted in a broad consensus regarding further procedures and was important for developing a strong feeling of mutual trust among the team members.

In this cross-national comparative research project the research team agreed to investigate how teachers of primary science created rich opportunities for engagement in learning and reasoning, and the impacts of local contexts and cultures on their practice. The study differs from other similar studies in that it focuses on culturally embedded practices and processes rather than output-oriented performance assessments.

The research project focused on the exploration of teaching and learning of scientific reasoning at primary schools in the three countries. The partners agreed to collect video-recordings of complete science units in each country using several cameras. The video-data thus collected were to be exchanged amongst the teams and jointly discussed. English was chosen as working language of the project, which meant that selected scenes of the German and Taiwanese video data needed to be translated and subtitled.

EQUALPRIME was not an intervention study. The researchers asked teachers who were locally recognised as 'good teachers' to agree to their teaching being video recorded and subjected to research analysis. Rather than single lessons, the team recorded entire teaching units. The teachers were explicitly asked to teach the way they normally would. The only condition was that the teachers should choose one of four topics agreed upon by the partners for reasons of comparability, which were all part of the curricula in the three countries. These were:

1. Physics: Forces (e.g., force and motion, floating and sinking, flight)
2. Chemistry: Changes of matter, states of matter (e.g., water)
3. Biology: Living things in their environments
4. Earth Science: Basic astronomy (e.g., how night and day occur; the phases of the Moon).

Research Questions

In the proposal for the Australian Research Council grant, the purpose of the study was summarised as follows:

> This project explores classroom teaching and learning in primary school science in three different countries to identify discursive practices that provide opportunities for quality reasoning and learning, and to explore the commonalities and differences in practice that relate to the different cultural-historical traditions in the three countries. In an era of increasing importance of science education and of global comparisons of countries' scientific literacy outcomes, we need to develop more definitive understandings of classroom practices that lead to quality learning, of culturally specific traditions from which we can learn in improving primary science education in Australia and internationally.

The study involved video capture and case studies of good teaching in each country, and a comparative analysis of these using multiple theoretical perspectives and new research technologies. The analysis focussed on: the framing of lesson sequences and classroom settings and teacher-student interactions that provide opportunities for quality learning and reasoning. According to the shared repertoire the research team had agreed upon the following set of research questions, while keeping in mind that further questions might arise in the course of the research process:

1. What are the characteristics of teaching and learning practices that offer productive opportunities for student engagement in quality learning and reasoning and the development of scientific literacy outcomes?
    1.1 What forms of classroom discourse provide opportunities for exploring ideas, reasoning with ideas and observations, and constructing understandings about natural phenomena?

1.2 What forms of classroom discourse develop students' competencies with the literacies of science including the development and refinement of students' representational resources?
1.3 What forms of classroom discourse support broader scientific literacy outcomes such as dispositional outcomes, understandings of the nature of science and its societal interactions.

2. To what extent and in what ways do teaching and learning practices differ in different cultures?

   2.1 What evidence is there for a coherent body of science teaching and learning practice in each of the countries?
   2.2 How do teachers in different cultures open up opportunities for students to engage in scientific reasoning?
   2.3 What are the similarities and differences in science teaching and learning practices in the different countries?
   2.4 How are these differences framed by teacher beliefs and particular cultural traditions?
   2.5 What different representations do children use in exploring questions about the natural world and in what ways are these culturally framed?

3. What are the implications for teacher education and for the improvement of pedagogical practices in science education?

Answers to these questions as well as further ones can be found in the different chapters of this book.

The Science Education Context

In most countries, the lack of science taught in primary schools is an issue, as is the struggle to get teachers to focus on higher-level conceptual reasoning in science. There are debates on the extent to which knowledge outcomes should dominate primary school science, or science investigation abilities, and what should be the place of social aspects of science.

In Germany, basic science topics have been part of the subject called *Sachunterricht* since the 1970s (cf. Möller et al. 2012). *Sachunterricht* (literally translated: 'teaching things') is a general subject, which is designed to give students a general introduction into different aspects of life deemed culturally important. Beyond natural science, this includes historical, social-cultural and geographical topics. Given the broad spread of topics it becomes clear why *Sachunterricht* is not taught by specialist natural science teachers. Rather, *Sachunterricht* is generally taught by the home classroom teacher. Only a small number of home teachers have studied science as part of their teacher training. Many teachers of *Sachunterricht* do not feel qualified enough to teach natural science topics.

In Australia, science in primary schools is a relatively young subject. It is well represented in curriculum documents but in terms of practice it has yet to achieve mainstream status, with many studies over the years identifying a lack of time being devoted to science, and teachers lacking confidence and competence in teaching it (e.g., Goodrum et al. 2001).

In Taiwan, on the other hand, greater emphasis is given to science education at primary level. The national curriculum guidelines of science and technology are implemented nation-wide, and most schools, at least in cities, are well equipped with science laboratories and sophisticated ICT resources. Further, science has been regarded as an important learning area, and is taught by specialist teachers at most primary schools.

In many countries, there is a history of noteworthy innovation in the teaching of science and the literature shows many examples of quality teaching and learning and innovative practices in the subject area (for Australia see Hackling et al. 2007; Tytler et al. 2004, 2009a, b. For Germany see Charpak 2006; Deutsche Telekom Stiftung und Deutsche Kinder- und Jugendstiftung 2011; Kleickmann et al. 2007; Möller et al. 2002, 2012; Wagenschein 2008. For Taiwan see Hsu and Wang 2012; Wang et al. 2011). A key challenge for all countries is how to transfer these theoretical insights and the many examples of good practice to mainstream teaching.

One of the issues of concern is that, while primary teachers in Australia and Germany have very good pedagogical skills and sensibilities and operate in a culture of teaching and learning that is learner-centred and focused on the whole child, they often do not have the knowledge of science concepts or science inquiry approaches that allow them to translate these skills and sensibilities into effective science learning experiences. On the other hand in Taiwan, more often now, science is taught in primary schools by specialist teachers.

In Australia, there have been a number of studies and projects such as *School Innovation in Science* (Tytler 2009; Tytler et al. 2004), *Primary Investigations* (Australian Academy of Science 1994) and *Primary Connections* (Hackling et al. 2007) that have promoted pedagogies which emphasise inquiry-based learning and the literacies of science and contexts that engage students in quality learning and reasoning. One of the difficulties, however, in promoting such pedagogies, is that descriptions of such principles as 'inquiry' and 'reasoning' and 'open ended questioning' at a broad level neither represent an understanding of how these operate or interact in supporting learning, nor signal to teachers the instructional moves and interactions with students implied by these terms.

It is well established that the teacher is a key factor in determining student learning outcomes. Meta-analyses have revealed that teachers account for 30 % of the variance in student achievement (Hattie 2003), which is a comparatively large share (see also, Tytler and Osborne 2011; Osborne et al. 2009). Barber and Mourshed (2007), in a large comparative study of education systems, concluded that successful systems focused on teacher-student-interactions in the classroom. Thus, a key factor in teachers supporting quality learning lies in the minutiae of teacher interactions with students in their execution of learning sequences.

In science education, attention has long been focused on the structure of learning sequences in supporting students to move from naïve perceptions of the natural world to engage with the often counter-intuitive ideas and practices through which science represents the world. Much of this attention arose out of the research into student conceptions in science and resultant conceptual change perspectives on learning and learning sequences (see, for example, Hubber and Tytler 2004 for an overview of conceptual change models, and Hackling et al. 2007 for a description of the 5Es structure of *Primary Connections*).

Thus, to understand how quality learning and reasoning in science is supported in primary classrooms, the EQUALPRIME team intended to study the fine detail of student-teacher interactions and the ways in which they are framed by culture, contextual factors and broader pedagogical beliefs, and also the structure of the way this occurs across multi-lesson learning sequences.

There are signs, especially in the preschool and primary school sectors, that more empirical research is now being conducted into teaching and learning processes. For example, cross-disciplinary characteristics of good teaching have been empirically identified by researchers such as Helmke and his working group, and also with recourse to international studies (Helmke 2006; Helmke et al. 2007; for studies in English, see Shuell 1996; Brophy 2000). Moreover, there have been a number of attempts, following Weinert and Helmke (1997), to determine teacher competencies (for example adaptive teaching competency (Beck et al. 2008; Rogalla and Vogt 2008). And finally, a number of studies have been conducted in the primary school sector that have ascertained effects of open learning in combination with specific instruction content (for an example of publications in German, see Möller 2006).

The recent debates on teaching and learning concepts have been strongly influenced by a modified learning theory paradigm which can be termed as “moderately constructivist instruction” (Einsiedler 2009; Wu and Tsai 2005). Based on the premise that every learning individual constructs his or her own meaning, instruction research emphasises the importance of the teacher’s scaffolding function which supports the students’ processes of meaning making in largely self-regulated interaction with the learning objects. In this research there is a general consensus that good teaching presupposes a successful balance between constructivist approaches and direct instruction (Jones et al. 1999; Pauli and Reusser 2006; Möller 2001).

Researchers have not yet found a satisfactory empirical answer to the question of how teachers manage to achieve a successful balance between instructing students directly and promoting the self-regulated construction of knowledge. In particular, only a few studies have furnished process-related data on the quality of primary school instruction or have explained why instruction affects different groups of students differently (Lipowsky 2007, p. 47).

Tytler et al. (2004), in an interview study of 13 primary and 6 secondary teachers of science who were considered effective teachers, identified a positive tension in these teachers’ practices between, on the one hand, a focus on the individual and on the community of learners; and, on the other hand between a focus on processes (i.e. the discursive practices of science) and products of learning (i.e. deepening understandings of scientific concepts). Each teacher presented a different way of working with these tensions. In a sense, these dimensions also represent complexities in the language through which teachers describe and make sense of their practice, and there is a need to further explore these dimensions through studies of quality classroom practice, captured in situ.

The Special Focus of EQUALPRIME

Comparative studies of school achievement have been conducted for many years now. As a result, we know more about the academic strengths and weaknesses of students in different countries, and how they compare with students in other countries. However, because of the nature of these studies, they provide little information on how to systematically improve teaching and learning (cf. Helmke 2006). The 1999 TIMSS video studies of Grade 8 science teaching in different countries made an important step in research that revealed something of the nature of science pedagogy and how it varied between cultural contexts (Roth et al. 2006). Unfortunately, sampling was limited to single lessons and therefore revealed little about how teachers orchestrate learning over sequences of lessons.

Greater attention is nowadays paid to the students' capabilities in thinking and reasoning across a range of situations including those involving social interactions in science classrooms. This places particular demands on teachers who may not themselves be fluent or confident in the flexible use of scientific reasoning. The EQUALPRIME team, in line with a global shift in perspective, has come to agree on the need for learner centred approaches in the teaching of science and a focus on reasoning as a major student learning outcome. This opens up questions regarding the appropriate role of the teacher.

The team also shares the conviction that the interaction between teachers' knowledge of the canonical forms and discursive practices of science, and students' generation and exploration of their own ideas and representations, involves a tension that is worthy of significant study and one in which culture may play a significant role. A cross-national study, therefore, offers the promise of new insights into this critical issue.

Thus, EQUALPRIME is a predominantly qualitative study with a distinctly ethnographic orientation that focuses on: the microstructures of teaching and learning in science classrooms and how they provide opportunities for student engagement in reasoning; and, how teachers orchestrate learning over sequences of lessons. Concerning the methodology, the EQUALPRIME team was able to draw on several years of experience of the much larger international research project on mathematics education *The Learner's Perspective Study* (Clarke et al. 2006). David Clarke has supported the EQUALPRIME project with valuable methodological advice on several occasions.

Research Design

All of the Australian, German and Taiwanese data for the EQUALPRIME study were collected following the shared repertoire negotiated between the research teams.

Sampling

In order for data to be comparable, the team decided on a number of criteria concerning the choice of students, teachers, schools and topics. The students were to be 9–10 years old, since the team was hoping to record more complex forms of reasoning, which would be less likely to occur in younger children.

The team agreed to select only ‘good’ teachers who were expected to foster scientific reasoning among the students. However, the question of which criteria should be applied in order to define ‘quality teaching’ remained an issue of discussion throughout the research process. For sampling purposes, it was agreed that the teachers should be considered good teachers by local peers as well as the local research team. While a certain variety in teaching practices was to be expected not only across, but also within countries, the team agreed not to seek out teachers applying exceptional teaching methods given the limited cases collected in each country. However, where possible the cases from each country were to reflect different types of schools that were broadly classified as schools well supported by parents, average schools and schools in deprived areas.

Finding ‘good teachers’ who were willing to have their lessons video-recorded proved quite challenging. The teams mostly resorted to teachers that were already in contact with the research team, for example, through their involvement in professional development programs.

Within each class a focus group of students was chosen for closer observation and additional interviewing. The focus group students were selected with the help of their teachers. While the group was to represent students of different abilities, all focus group members needed to be articulate and comfortable in talking to adults.

For comparative purposes the team agreed to record teaching units of four science topics that can be found in the primary school curricula of all three countries involved in the research (see above!).

Data Collection

Data collected involved video and audio recordings of two to six science teaching units in each country. Consistent with the socio-cultural/socio-constructivist approach shared by the team members, two to three cameras were used in order to capture teacher-student and student-student interactions. In addition teachers were asked about their beliefs, practices and teaching goals in lengthy interviews before the beginning of the unit and in shorter interviews before and after each lesson. Students of the focus group were also interviewed after each lesson. Video-stimulated recall interviews were carried out with teachers and students at the end of the unit. Teaching material and student artefacts were also collected, as well as background information concerning the class and school.

Observations normally began with a period of fieldwork during which a research associate sat in the class in which the video recording was to be made at a later date. This period of fieldwork served to build up a trusting relationship with the class and the teacher and to collect information on basic sequences during lessons and on the social and interaction structure in the class. Towards the end of this phase, a camera operator occasionally was present during lessons and made trial recordings so that the children could get accustomed to the camera team. Following the initial fieldwork phase, an entire unit conducted by the teacher on a topic in the area of science-related learning was recorded on video. A research associate and the camera operator were present at all times.

Two to three cameras were used to record the lessons. The sound was recorded by a radio microphone worn by the teacher. The second camera moved around flexibly, and concentrated on selected focus groups of students who were equipped with movable radio microphones that lay on the tables. Sometimes the children themselves took the microphones with them when they changed their place. The German team used a third camera fixed on a tripod that captured the entire classroom activity from a higher point of view behind the teacher's front desk (Fig. 1.1).

During each lesson a member of the research team took field-notes using a structured observation sheet. Furthermore, at the beginning of the lesson unit, the teacher or the researchers used interviews, concept maps, small written surveys or graphic illustrations to gain an insight into the students' preconceptions about the topic of instruction. Comparable methods were employed at the end of the unit in order to assess the learning of the students over the topic (pre-post comparison). The teachers were asked about their views of the lessons in semi-structured video-stimulated recall interviews.

Data Sharing

In view of the amount of data collected, the team decided that local teams were to carry out a preliminary analysis and choose data deemed of particular interest to the purpose of the study. All team members received all video data recorded by each team and a detailed story line of each unit enabling all international partners to understand the focus and sequence of the lessons (Fig. 1.2). However, only a limited number of scenes were transcribed and translated into English, which functioned as the working language of the team. In order to comply with data protection

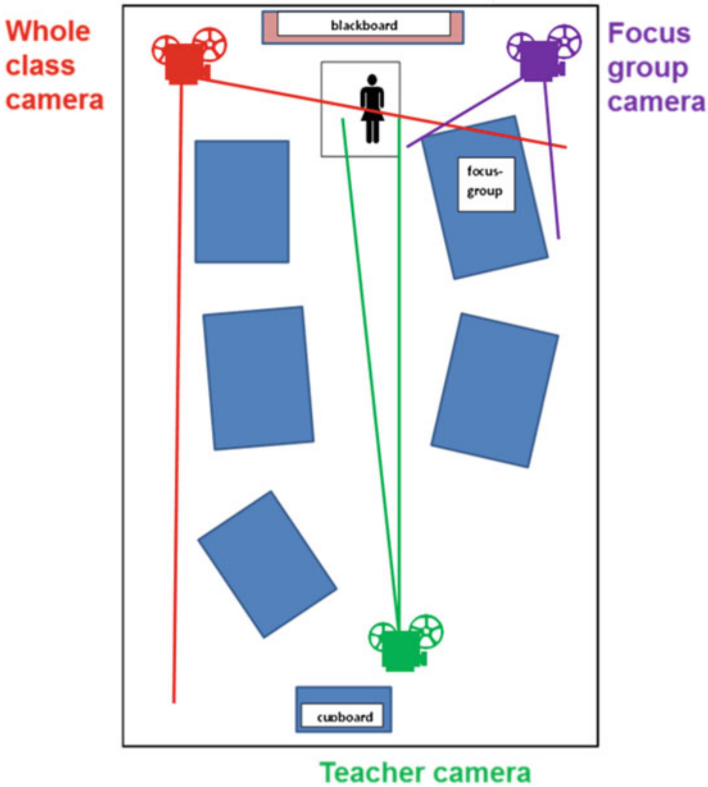

Fig. 1.1 Camera positions

standards, video data were never shared via the internet; and, were not and will not be published on the net. Data were exchanged at meetings of the international partners, which took place at regular intervals.

Analysis

As mentioned earlier, the large amount of data, much of which was recorded in languages not familiar to all project partners, led to the decision that the local teams should undertake a pre-selection of data to be translated. The local teams analysed the data collected and selected episodes or whole lessons that contained particularly interesting examples of teachers providing rich opportunities for student reasoning.

In a second step, each team analysed local and foreign data according to their particular research interests and corresponding methodology. For most analyses qualitative methods were used, which meant that codings were not pre-defined but

1 9/2	時間 m	時間 s	歴時 m's"	歴時 (s)	Activity	Photo	C	S
1	11	3	2'53"	173	分享希臘的月亮傳說故事與影片欣賞 Share the legend of the moon in Greece and watch a video.		T	W
1	13	56	2'01"	121	討論「月亮是什麼樣子?」 Discuss "What does the Moon look like?"		T	W
1	15	57	4'39"	279	月亮表面顏色深淺的圖案想像 Image the picture from the shadow of the Moon.		T	W
1	20	36	0'54"	54	以玉兔的樣子舉例示範 Demonstrate the shape of the "the Jade Rabbit "		T	W
1	21	30	3'28"	208	學生上台在電子白板上畫出自己的想像 Students draw their image in Electronic Interactive Whiteboard.		T	W
1	24	58	6'56"	416	各自完成習作中有關月亮表面圖案的想像畫 Complete drawing their image from the shadow of the moon in the exercises.		T	W

Timeline (Moon) Taiwan 1

Fig. 1.2 Story line of a Taiwanese astronomy lesson (Note. *C* camera, *T* **t**eacher camera, *S* instructional setting, *W* **w**hole class activity)

rather developed from the data. In addition some quantitative analyses were carried out where this was deemed important for the interpretation. The majority of the data coding was carried out using computer software, namely *Studiocode* on Macintosh computers and *Videograph* on Windows systems. For transcriptions and subtitling of the videos the team used *InqScribe* computer software which turned out to be very easy to use. In addition to video and audio data, other forms of data collected such as school documents, teaching resources, students' artefacts and interviews were all translated and distributed to all team members with the video data for each case. Data analyses varied depending on the particular research interest and methodological approach of each team.

International Team Meetings

Regular meetings of the EQUALPRIME team were a very important part of the research process. The team met at least once a year at different locations. Meetings were scheduled to coincide with international conferences, at which EQUALPRIME team members presented preliminary findings from the research project. Alongside the conferences the team members met for data exchange and intense discussions.

Joint analysis sessions of video data led to enriching exchanges of insider and outsider perspectives.

As had been agreed in the shared repertoire, all interpretations of data were to be cross-checked and authorised by the local team which had collected the data in order to minimise bias and misunderstandings due to lack of cultural awareness or local background information. While the insiders' perspective was given priority in final data interpretation, the outsiders' view was deemed equally important for gaining new perspectives and noticing aspects that were taken for granted by local teams. Face-to-face meetings were therefore very important for the on-going research project.

School Visits

Over the course of the project the team met several times in each of the participating countries. In addition individual research team members spent extended periods of time as visiting scholars of one of the partner institutions. On these occasions the local teams organised visits to the schools involved in the project as well as to other schools. The non-local members thus gained a broader view of teaching and learning practices in the countries involved and of contextual factors framing these. Classroom visits and observations of teaching by the case-study teachers allowed the team members to view teaching from new perspectives and enrich their in-depth analysis of video recorded sequences. Conversations with the teachers and with school directors and other members of the teaching staff were also helpful in this respect.

Data Protection Agreements

While it is quite easy for educationalist to video-tape classroom scenes in Taiwan and use the material for scientific discourse, data protection laws in Germany and Australia make filming in schools a bit more complicated. Germany has particularly strict laws on privacy. This is a consequence of the experience with two dictatorships in the past century when the secret services spied on nearly everybody and political persecution was notorious. Nowadays, people in Germany tend to mistrust any data collection and taking pictures of children in schools is normally forbidden. Making videos of children at school even for educational purposes not only requires the approval of the school authorities but also the written consent of every single parent. It is very difficult to get consent to upload videos or even still pictures taken in a school to the Internet.

Therefore, the whole international team had to sign an international data protection agreement stating that all the videos taken in the project are only available to

EQUALPRIME team members. They can be presented by the team members in closed meetings and at conferences and other scientific occasions for the purpose of scientific discourse or teacher training. However, it is forbidden to upload the videos on the internet or to hand them over to third parties.

Methodological Challenges

The use of videos in cross-cultural research enables researchers from faraway places to look inside classrooms in distant countries whose language and culture they may not be familiar with. They might be caught by the power of the images. The power of the image has been critically discussed in this context (Ulewicz and Beatty 2001). Watching hours of videotape from classrooms in a foreign culture may mislead researchers to feel as experts, and forget that what they have seen is only a very limited detail of the wider picture. Thus limiting the dangers of cultural bias was a central concern of the team in designing the research approach.

As we know, methodological choices concern all levels of research, from data collection through coding and analysis. Given the connection between theory and method, designing a research project with partners from different countries and cultures becomes a particularly challenging endeavour. Research traditions and corresponding methodological preferences differ as much across cultures and/or nations, as do teaching and learning practices. While multiple perspectives may be seen as enriching for the research project, the team must agree on some central positions regarding the theoretical approach, which will then influence decisions on methodological questions regarding data collection and analysis. This requires the team to develop a shared language, which is, in itself challenging given the multitude of languages and perspectives.

Teaching, including science teaching, is primarily transacted through language. None of the research team members spoke all three. This led to a number of problems to which the team had to find solutions. These are discussed in detail in Chaps. 11 and 13.

At the 2012 AERA conference in Vancouver the EQUALPRIME researchers Tytler, Hubber and Chittleborough listed a number of other problems with cross-cultural comparisons:

- The need to include a range of reasoning constructs to make comparisons across countries, and also within countries.
- The difficulty of developing coding, that researchers in each country can apply, for direct quantitative comparison. The comparisons will need to be more layered than this.
- In making judgments of teacher support, the need to capture not only dialogue, but also details of the nature of the task and its framing.

- The need to take an ethnographic approach based on visual data of student representation construction or interaction with artifacts, and of teacher interaction. Counting of coding categories will need to be subservient to wider framing of differences.
- If student responses are brief, and closely shaped by the teacher, can we infer reasoning? Is classroom talk unduly privileged by our methodology?

All these problems will be discussed in detail in the following chapters of this book.

Summary

EQUALPRIME is an exceptional educational research project in that science lessons on similar topics were filmed on three continents, which allows for unique comparisons of the school systems, teaching practices in the particular classrooms as well as the conditions of teaching and learning in the individual case study schools. The intention of the authors; however, is not to compare in a sense of ranking, but rather to compare the way teachers provide learning opportunities under differing conditions in order to gain new perspectives and question presumptions through an exchange of views on the cases in a cross-cultural setting. While the studies point to the impact of local cultural factors on individual teaching practices, the cases are by no means to be seen as representative of general teaching practice in the countries involved. Rather, the exemplar cases recorded in this study are examples of teaching practices which, while clearly influenced by local norms, expectations and regulations, never-the-less divert in many respects from mainstream teaching practice in their respective cultures. The video data are extraordinarily valuable for further research in the coming years and are already being used by the research team members in professional teacher education programs with great acclaim. The data enable profound insights into the process structures of quality science education as well as into the underlying cultural conditions for each case study and how they shape practice. The EQUALPRIME project may be seen as a practical example of how to organise and carry out productive international cross-cultural cooperation in the field of comparative education for the benefit of the scientific community.

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Chapter 2
Social and Cultural Factors Framing the Teaching and Learning of Primary Science in Australia, Germany and Taiwan

Mark W. Hackling, Hsiao-Lan Sharon Chen, and Gisela Romain

Introduction

The nature and quality of teaching and learning in a classroom and the achievement of students can be understood as outcomes that emerge from interactions amongst layers of a complex system. Classrooms and schools are embedded in complex and layered social and cultural contexts that influence the development of students, teachers and schools. Johnson (2008) and Lewthwaite (2006) have applied Bronfenbrenner's (1989) ecological systems theory to explain the development of schools and teachers. Johnson (2008, p. 3) explains that "parental expectations regarding the academic and extra-curricular success of their children can often create a dynamic that directly and indirectly impacts the atmosphere and climate of the school". The school is also seen as being set within the broader "social blueprint of a given culture … (which) consists of the overarching pattern of values, belief systems, lifestyles, opportunities, customs, and resources" (p. 3). Lewthwaite (2006) described the spheres of influence surrounding science teachers spreading out from their own particular knowledge and beliefs to the expectations and support of teacher colleagues, expectations and priorities of the school, parental and community aspirations for science teaching and learning, and the government's curriculum policy and priorities for teacher professional learning. Science teaching and learning needs to be viewed as a "cultural-contextual process influenced by attributes of the individual, and the various levels of environment" in which it is situated

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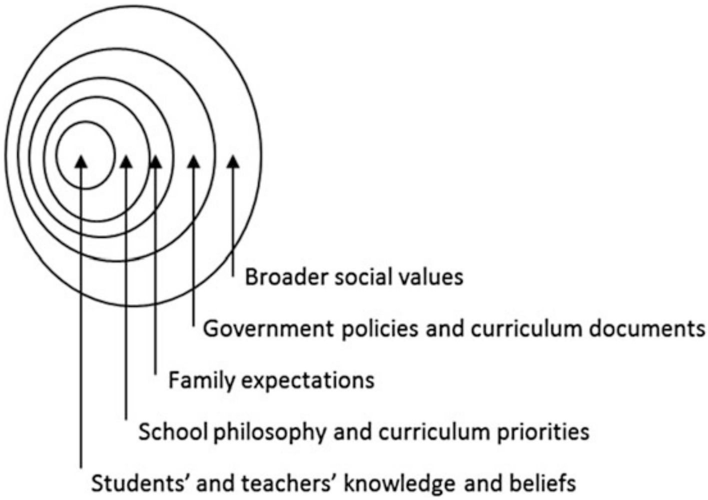

Fig. 2.1 Layers of social and cultural factors influencing classroom culture and pedagogy

(Lewthwaite 2006, p. 346). Figure 2.1 illustrates these layered spheres of social and cultural factors that influence the culture of the classroom and its pedagogy.

Erickson (1986) described culture as "learned and shared standards for ways of thinking, feeling and acting" (p. 117). Culture is widely recognised as strongly influencing education policy and practice and as Alexander (2000, pp. 29–30) explained "Life in schools and classrooms is an aspect of our wider society, not separate from it: a culture does not stop at the school gates". The character of schooling is shaped by the values that shape other aspects of national life. Schooling is part of a country's culture and curriculum can be viewed as a cultural artefact (Cogan et al. 2001). In summarising broad cultural and philosophical influence on Chinese education, Tao et al. (2013, p. 35) note that:

> Education in China is profoundly influenced by Confucian philosophy... Transmitting Confucian morals, imparting knowledge, and resolving doubts are the major responsibilities of teachers. Students pay great respect to teachers and are also attentive to books, which are regarded as beneficial and sacred and the study of books, reading and self-reflection are recommended learning strategies.

However, Mason (2007) cautions researchers in making cross-cultural comparisons as "They face possible accusations of stereotyping, of treating cultures as monolithic, and of overstating its influence in a hybrid world characterised by complex interactions and influences" (p. 166), a view consistent with the ecological systems and complexity theories. Globalisation, plurality, multiculturalism, class, gender and racial divides ensure that few societies are culturally homogeneous which suggests that comparing classrooms across cultures should focus strongly on the local contextual factors influencing schools, such as socioeconomic status, as these are likely to impact more directly on teaching and learning than broader social values.

Table 2.1 Performance of Australian, German and Taiwanese Grade 4 students on 2011 TIMSS science assessments

Country	Rank	Overall average scale score	Knowing average scale score	Applying average scale score	Reasoning average scale score	Percentage of students	
						Low benchmark[a]	Advanced benchmark
Taiwan	6	552	542	552	568	15	15
Germany	17	528	524	533	526	22	7
Australia	24	516	517	513	518	28	7

[a]Shown as the percentage of students failing to reach the TIMSS intermediate benchmark

Each of the three countries participating in the *EQUALPRIME* project (Australia, Germany and Taiwan) has a fine tradition of primary science education. In the 2011 TIMSS study (Martin et al. 2012) of 45 participating countries at the Grade 4 level, Taiwan was ranked sixth with an average scale score of 552, Germany 17th (528) and Australia 24th (516). The mean scale score for all three countries was significantly higher than the TIMSS scale centre point of 500.

Given the interest of governments and science educators to promote high standards of achievement and higher order thinking and reasoning, it is useful to examine the performance of students on the TIMSS cognitive domains and against the TIMSS international benchmarks (Table 2.1).

Not only did the sample of Taiwanese students have a higher average scale score than the German and Australian samples, the Taiwanese sample also achieved a higher score in the reasoning domain, had a higher percentage of students achieving the advanced international benchmark and fewer students failing to achieve the intermediate benchmark than the German and Australian samples. The greater than 20 % of students failing to reach the intermediate benchmark in the German and Australian samples would be of concern to education authorities. These underperforming students are most likely to come from lower socio-economic groups and migrants speaking a foreign language.

There has been increasing interest in international comparisons of teaching and learning extending from the TIMSS and PISA comparisons of achievement to video studies that compare pedagogical practices of teachers from different countries and cultures. Video capture of classrooms across national boundaries has raised questions about the varying foci of teaching and learning including the relative attention to reasoning in science classrooms (Lokan et al. 2006; Stigler and Hiebert 1997) and the possibility of significant cultural determinants of classroom practice (Stigler and Hiebert 1998). Given that teaching and learning are embedded in culture (Alexander 2000), any comparisons of teaching across countries needs to take account of the contextual factors that shape the culture of teaching in those countries.

Purpose

This Chapter provides a framework to consider the broader sociocultural and contextual factors that shape the ways in which teaching and learning are transacted in Australia, Germany and Taiwan. This framework considers the social values, government policies and curriculum emphases, teacher education, family and school expectations that frame teaching and learning. This framework provides context to the Chapters that follow which document the teaching and learning of science in the three countries. The framework identifies the sociocultural and contextual factors that may help explain differences in science teaching practices between Australia, Germany and Taiwan.

Australia

Australia is a large island continent and the sixth largest country in the world with an area of 7,686,850 km^2 and a population of 23 million. The Australian economy is dominated by the services sector, mining and agriculture and most exports are of primary products. Australia's manufacturing sector is in decline. Australia is a multicultural society as it has accepted migrants from many different countries and cultures who now vastly outnumber the original inhabitants.

Australia is a product of a unique blend of established traditions and new influences. The country's original inhabitants, the Aboriginal and Torres Strait Islander peoples, are the custodians of one of the world's oldest continuing cultural traditions. They have been living in Australia for at least 40,000 years and possibly up to 60,000 years. The rest of Australia's people are migrants or descendants of migrants who have arrived in Australia from about 200 countries since Great Britain established the first European settlement at Sydney Cove in 1788 (Australian Government, Department of Foreign Affairs and Trade 2012). Up to 1945, the Australian population was largely Anglo-Celtic and subsequent waves of migration came from Europe and then from the Asia-Pacific region, the Middle East and Africa. As at June 2013, 28 % of the Australian resident population was born overseas. Those born in the UK continued to be the largest group of overseas-born residents, accounting for 5.3 % of Australia's total population, followed by persons born in New Zealand (2.6 %), China (1.8 %), India (1.6 %) and Vietnam (0.9 %) (Australian Bureau of Statistics 2013).

Modern Australia emerged as a result of migration and the establishment of the separate colonies of New South Wales (1788), Tasmania (1825), Western Australia (1827), South Australia (1836), Victoria (1851) and Queensland (1859). In 1901, the colonies combined into the Commonwealth of Australia as a federal political structure broadly based on the Westminster system. The Australian federal government took responsibility for collection of income taxes which were initially returned to the states on a per capita basis. School education remained the responsibility of the states whilst the Australian government assumed responsibility for matters of national significance such as defence. In 1902, Australia was the first country in the world to give women both the right to vote in federal elections and also the right to be elected to the national parliament; however, Indigenous people were not allowed to vote in federal elections until 1962 (Australian Government, Department of Foreign Affairs and Trade 2012).

As described above, Australia is a culturally diverse nation. Although most Australians live in the capital cities of the states, the population is widely dispersed over a large land mass and there is also a wide spread of socio-economic status across the Australian population. This diversity is reflected strongly in measures of educational attainment (e.g., Thomson et al. 2013). The seven Australian EQUAQLPRIME case studies were drawn from two of the eight Australian states and territories (Victoria and Western Australia) and mostly from capital cities within those states which limits the extent to which they can be considered representative of such a diverse nation.

Structure of Schooling

Australia comprises eight states and territories which have constitutional responsibility for providing school education. In Australia, schooling is provided by three education sectors within each state. The largest sector comprises Government schools which are governed by state education department policies and procedures, followed by the Catholic Education schools which are governed by the Catholic Church, and the Independent school sector is the smallest and comprises schools sponsored by the protestant churches and philosophically framed schools such as Montessori and Rudolf Steiner schools. Non-government schools are financed by government funding and by fees paid by parents. Parents do not pay fees for students attending Government schools; however, there are costs for uniforms and charges for some educational materials, resources and special programs. Approximately two-thirds of students attend Government schools and one-third attend non-Government schools. The Catholic Education sector enrols approximately 20 % of students and Independent schools enrol approximately 13 % of students.

Australian schooling develops through three phases; pre-school, primary school and secondary school; however, there is some variation between the states in the nature of pre-schooling and the nomenclature used to describe it. In most states there are 2 years in which students attend part- or full-time pre-schooling. In all states it is compulsory for children to attend school in the year that they turn 6-years of age. Grade 6 is the final year of primary school and students complete 6 years of secondary schooling. It is expected that all students will be engaged in some form of full-time education or training until they attain 17-years of age.

Most Australian primary and secondary schools provide a comprehensive schooling for the full range of student abilities in a co-educational setting. Some non-Government schools are not co-educational and provide for only boys or girls.

In only one of eight Australian states is a compulsory external examination used as a component of assessing and grading students at the end of Grade 10. In all states, Grade 12 students who wish to gain admission to university education must sit for state-wide external examinations and entry to courses is competitive based on the student's Tertiary Admissions Rank (a percentile score) so that entry to high status courses such as medicine requires very high rank scores.

Australian Values and Educational Philosophy

Australian values have evolved from the broadly Anglo-Christian values of the early British settlers and were shaped by the experiences of World War I. The Australia Government states that:

> Australian society values respect for the freedom and dignity of the individual, freedom of religion, commitment to the rule of law, Parliamentary democracy, equality of men and women and a spirit of egalitarianism that embraces mutual respect, tolerance, fair play and compassion for those in need and pursuit of the public good. Australian society values equality of opportunity for individuals, regardless of their race, religion or ethnic background. (Australian Government, Department of Immigration and Border Protection 2013, p. 1)

These values are often referred to more colloquially as principles of 'mateship' and 'a fair go' and point to the valuing of inclusivity and opportunity for all, especially through education. Given the critical role of education for migrant peoples to establish themselves in a new country, it should be noted that first generation Australian born children of migrant parents are the highest performing students when country of birth is considered (Thomson et al. 2013).

Parsons and Carlone (2013) explain that patterns of behaviour, language use, use of space and time that characterise the culture of schooling reflect the values and beliefs of the dominant culture. This means that students from non-dominant groups must take up the behaviours and language of a second culture to be successful in school; this is very significant for a multicultural society such as Australia and particularly for Australian Indigenous students who represent only 2.5 % of the Australian population. National assessments of literacy, numeracy and scientific literacy all demonstrate the powerful influence of socio-economic factors in school achievement in Australia. Concerns about the school readiness of children from disadvantaged families have been addressed with an increased attention to the provision of educational opportunities prior to the commencement of formal schooling.

There have been a number of influences on Australian science education philosophy and one of the most significant has been Peter Fensham's (1985) seminal essay on 'science for all' which argued that science education should not be solely focussed on educating the most able to be professional scientists and that schools should provide a broad science education for all children to develop what we now describe as scientifically literate citizens. The 'science for all' philosophy is consistent with Australia's egalitarian values.

The research teams of Roger Osborne (Waikato University) and Rosalind Driver (University of Leeds) which led research into children's conceptions about natural phenomena heralded the emergence of more constructivist and child-centred philosophies of science education in Australia, which challenged transmissive views of teaching and learning. The British focus on investigating that was adopted in the first Australian national curriculum under the banner of *Working Scientifically* (Curriculum Corporation 1994) strongly established an investigative approach to inquiry in Australian science education and this focus on inquiry and scientific literacy for all students was further endorsed by the national review of Australian science education (Goodrum et al. 2001). Most recently, Tytler's (2007) call for a re-imagining of school science advocated strongly for greater student agency in learning, the need to place science in meaningful and contemporary contexts and to widen the range of learning outcomes to better engage students in learning science and to better prepare them for the world in which they will live. These philosophical principles of scientific literacy for all students, investigative and inquiry oriented learning, child-centred and constructivist approaches which give students agency in learning are most strongly represented in Australian primary science education, and to a lesser extent in secondary schooling.

Australian Science Curriculum and Assessment

Australia comprises eight states and territories which have constitutional responsibility for education. The Australian national government collects most taxes and makes a significant contribution to funding schooling. There is therefore a tension between national and state governments for control of curriculum. Prior to 1994 all states and territories developed their own science curricula. In the early 1990s, national curriculum and assessment frameworks for science were developed; however, in 1994 they were abandoned in favour of state developed curricula. In 2009, the Australian Curriculum and Assessment Authority was established and it managed the development of the Australian Curriculum for Science which is currently being implemented in most states and territories for students in years up to Grade 10 (ACARA 2012).

There has been a powerful interplay between curriculum documents and curriculum resources which has influenced the implemented primary science curriculum in Australia. In the 1950s and 1960s primary science was largely based on nature study in the absence of resources to support teaching of physical sciences. During the 1970s and 1980s the individual state governments progressively developed science curriculum documents and support resources that included the physical sciences, and science process skills. It should be noted that text books are not a tradition in

Australian primary science teaching, and teachers utilise a range of documents and internet based resources. The Australian Academy of Science's (1994) *Primary Investigations* curriculum resources supported a national approach to inquiry oriented science using a cooperative learning approach with foci on investigating and the four conceptual strands of science (biology, chemistry, earth sciences and physics). The Australian Academy of Science's (2005) *Primary Connections* curriculum resources supported a national approach to science with foci on investigating, literacies of science, assessment for learning, and a cooperative learning approach. The resources supported a large-scale professional learning program (Hackling et al. 2007). These resources are being used by a majority of Australian schools to support the implementation of the new Australian science curriculum.

The Australian science curriculum has a focus on developing learning outcomes that contribute to students' scientific literacy and states that the curriculum:

> …provides opportunities for students to develop an understanding of important science concepts and processes, the practices used to develop scientific knowledge, of science's contribution to our culture and society, and its applications in our lives. The curriculum supports students to develop the scientific knowledge, understandings and skills to make informed decisions about local, national and global issues and to participate, if they so wish, in science-related careers. (ACARA 2012, p. 1)

The Australian science curriculum (ACARA 2012) is organised into three strands which are expected to be taught in an integrated fashion:

- Science understandings: biological, chemical, earth and space, and physical sciences.
- Science as a human endeavour: the nature and development of science, the use and influence of science.
- Science inquiry skills: questioning and predicting, planning and conducting, processing and analysing data and information, evaluating, and communicating.

Many Australian primary teachers integrate science with other subjects using a thematic approach rather than teaching science as a separate subject and because of this it has been difficult to accurately quantify how much time has been devoted to science. Teachers often allocate 1-h per week for teaching science; however, there have been attempts in some states to increase this e.g., South Australia is encouraging teachers to provide 90 min per week for years up to Grade 3 and 120 min per week for Grades 4–7. Despite these attempts, there is a history of science being badly underrepresented in the primary school curriculum. The implemented science curriculum is often planned cooperatively by teachers who teach at the same grade level in larger schools and there has been considerable flexibility in how curriculum documents are interpreted.

Assessment of primary science achievement in Australia is highly idiosyncratic with each teacher making on-balance judgments about the quality of learning demonstrated by the students drawing on evidence that they have collected during the course of the teaching period. Teachers are expected to use the Australian Curriculum content and achievement standards as a guide to awarding A–E grades which are reported to parents twice per year. There is an absence of standardised testing for summative assessment purposes as entry to secondary schools is not dependent on grades achieved in primary education.

School Governance and the Role of Parents

There is a long standing Australian tradition of parents supporting primary schooling but not having any significant influence over school policies or pedagogy; this is left to the professionals. Most primary schools have a Parents and Citizens Committee which mainly supports the school by fundraising and organising social activities. There is an increasing move to decentralisation of educational management from central education departments to schools themselves and this has resulted in schools establishing school boards that have some oversight of school priorities and some policy issues such as the nature of the school uniform. School boards typically comprise teachers, parent representatives and some community members co-opted to the boards on the basis of expertise. Despite the decentralisation of management responsibilities, all significant policies are determined by state and national governments.

Teachers and Teacher Education

Most primary school teachers in Australia are generalists; they teach most subjects to their own class and this is consistent with a common approach to programming instruction where a theme is used to integrate the teaching of language, number, social sciences, science and technology. In a small number of schools, one teacher who has developed interest and expertise in science teaching may act as a specialist science teacher or mentor other teachers to enhance their teaching of science.

A full-time primary school teacher typically delivers 22 h of instruction to children each week and has 6 h of duties other than teaching which provides some time for administrative duties, preparation and marking.

Almost all teachers in Australia have completed 4-years of education at a university. Primary teachers normally complete a 4-year Bachelor of Education degree or a 1-year Diploma of Education degree after a 3-year BA or BSc degree or, increasingly, a 2-year Master of Teaching after a BA or BSc. Most primary teachers have not studied high level mathematics or science in Grades 11–12 and only study between one and three science units in their pre-service teacher education. There is extensive research to show that most primary teachers feel ill-prepared for teaching science and have low confidence and self-efficacy for science teaching. For example, Angus et al. (2007) study of Australian primary schools found that only 18 % of primary teachers believed they had all the expertise they needed to teach science while 35 % believed that they had all the expertise they needed to teach mathematics.

The Australian Institute for Teaching and School Leadership has established national professional standards for graduate, proficient, highly accomplished and leader teachers (AITSL 2012). University faculties of education are being held accountable for the quality of their programs and graduates through state-based accreditation processes and teachers must be registered by the local state or territory board before they can be employed to teach. To maintain registration to teach in schools, teachers are expected to complete a minimum of 20 h per year of professional learning. Although starting salaries for teachers compare favourably with other mid-range professions, Australian teacher education courses do not attract the most academically able school leavers.

Typical Science Classrooms

Very few Australian primary schools have a purpose built science room; most science lessons are taught in the 'home' classroom. Classes are usually of 25–30 children, often wearing a low cost uniform sitting at individual desks arranged into groups. Classrooms are 'dressed' with posters and other artefacts and a space with a mat at the front of the room, next to the teacher's desk where children will sit for class discussions with the teacher. Most science lessons will involve some hands-on activity work conducted in small co-operative learning groups. Investigations typically utilise everyday objects and materials rather than specialist science equipment used in secondary schools. Classrooms are often congested and there is little space for storage of science materials and for group activities. Science activities are therefore often conducted in areas outside of the classroom. Most schools have a wireless network and children often have access to laptops or iPads. Interactive whiteboards are found in many classrooms.

Germany

Germany is a modern industrialised country in central Europe. With the fall of the Berlin Wall in 1989 and the collapse of the Soviet Union, East Germany was reunited with West Germany in 1990. Germany has an area of 357, 021 km^2 and a population of 80.5 million which is decreasing steadily due to a low birth-rate. About 20 % of the population are first, second or third generation immigrants. Immigrants mostly live in West German states including former West Berlin. Among the group of 0–15 year-olds, immigrants make up almost a third of the population (Statistisches Bundesamt 2014a) and in Berlin, more than 50 % of the 0–5 year-olds have an immigrant background (SenBJW 2014). The former West Germany was one of the founding countries of the European Union and the Eurozone and Germany remains one of the economic powerhouses of Europe, contributing about one quarter of the Eurozone's annual gross domestic product. It is one of the leading countries in terms of exports.

Germany comprises 16 federal states that are collectively referred to as *Länder*. Each state has its own state constitution and is largely autonomous in regard to its internal organisation and education system. Following the reunification, the East German states adapted the West German political model and education systems were also largely adjusted to West German systems (Döbert 2007). Since our EQUALPRIME research was conducted in schools in the former divided city of Berlin and the surrounding former East German state of Brandenburg the following description mostly relates to the characteristics of education in these two states in particular. Berlin has recently introduced a new teacher training law and Berlin and Brandenburg have jointly drafted a new comprehensive curriculum for all subjects for Grades 1–10, which will be implemented as of August 2016. However, since data for this study were collected between 2011 and 2013, the following information refers to facts and figures at the time of data collection.

Structure of Schooling

The German educational system is not a unified whole, rather responsibility lies with the government of each of the 16 states. In order to achieve a certain amount of comparability between standards and recognition of certificates across the Federal Republic, the Standing Conference of the Ministers of Education and Cultural Affairs (Ständige Konfererenz der Kultusminister der Länder der Bundesrepublik Deutschland, referred to as KMK) in the Federal Republic of Germany meets regularly to agree on joint standards. Agreements then have to be ratified by each state.

German state schools are free of charge and generally co-educational. In some states, parents have to pay for schoolbooks and additional learning materials. Private schools have increased by nearly 70 % between the early 1990s and the present (Statistisches Bundesamt 2012). Currently around 8.5 % of students attend private schools with many of these being denominational schools or reform oriented schools such as Montessori and Waldorf schools. Private schools can apply for government funding, provided they comply with local school curricula. Fees for private schools are often income-related and rather low compared to other countries.

Day-care is provided in some states for toddlers and 95 % of all children attend a Kindergarten from the age of 4 (Autorengruppe Bildungsberichterstattung 2014). Primary school generally starts at the age of 6 and lasts for 4 years in all states except for Berlin and Brandenburg, where primary education lasts 6 years. Children are then tracked into different forms of secondary schooling according to grades and assumed abilities. Currently around 40 % of all children attend a *Gymnasium* [grammar school] for 6 or 7 years which leads to the *Abitur* matriculation examination and on to university (Statistisches Bundesamt 2014b). Some students also opt for comprehensive schools. About one fourth of all students attend the *Realschule* until Grade 10 and then continues with vocational training which often consists of a dual system of theoretical learning and training on the job or vocational school. The remaining 10–15 % of students is sent to the *Hauptschule* and exits at the end of Grade 9 or 10 with considerably less chance of continuing their education or finding a job. In some states, among them Berlin, the *Realschule* and *Hauptschule* have recently been merged into an integrated secondary school model, while Brandenburg like several other former East German states opted not to introduce the *Hauptschule* following reunification and offers students the choice between a comprehensive secondary school and the *Gymnasium*.

Children with special needs were traditionally sent to special schools. However, in Berlin more than 50 % of students with special needs attend regular schools; and, since Germany has ratified the UN Convention on the Rights of Persons with Disabilities, efforts are currently undertaken towards inclusion in regular schools.

German primary schools are traditionally half-day schools with educational programs ending by 1.30 pm at the latest, although especially in Berlin and in former East German states day care was often provided in the afternoon. Recently, whole-day school models have been promoted by the state nationwide, in part to meet demands of working parents and in part with the aim of offering additional support for students from underprivileged backgrounds.

Teachers are completely free to choose their teaching methods and materials. Specialised publishing houses provide a selection of school books and parents are presented with a list of books needed for each topic at the beginning of every school year. Teachers often resort to photocopied worksheets. The use of internet resources has risen markedly over the past decade and interactive whiteboards (IWBs) are increasingly available, though many older teachers lack the skills to use these (Drossel et al. 2012).

School curricula are decided by each state. However, recent common standards for the main subjects, i.e. German language, mathematics, science and English agreed upon by the KMK have been influential in defining the content of curricula. Curricula have also been changed from input- to output-oriented and now are structured along standards and competencies in many states.

German Values and Educational Philosophy

The German education system remains influenced by the idealist philosophy of Humboldt, who espoused the ideal of *Bildung*. The term *Bildung* literally means ‘formation’, but also ‘education’ and ‘cultivation’ (Gellert 2001). This cultivating and drawing out the intellectual and cultural development of the individual has remained a central tenet of German education. In the late nineteenth and early twentieth century the German reform movement advocated a strongly child-oriented pedagogy and experimented with alternative forms of teaching and learning. Many of these ideas and ideals have remained influential or regained popularity, in primary schools, especially with reform-oriented teachers and parents. The experience of the totalitarian regime under Hitler and resulting Holocaust as well as the more recent experience of life in the former communist ruled German Democratic Republic are still strongly present in the collective memory of the nation and democracy education is an essential part of the curriculum.

The German education system is based in theory on meritocratic principles, i.e. children's chances to succeed within the education system should depend on their personal ability and not on their social status or family background. Results of the Biju study carried out in 1991/1992 shortly after the reunification pointed to significantly higher results of students in East German states especially in physics and biology (Baumert et al. 1997). However, according to TIMSS results from 1994/1995 the differences were no longer as pronounced (ibid.). The results of PISA 2001, the first international general assessment Germany had taken part in for several decades (not counting TIMSS in 1995) sent shockwaves through the country (Hansel 2003). Contrary to the ideal of equal chances, the results pointed to a particularly high correlation between family background and school success, higher than in almost any other of the participating countries (Baumert et al. 2003). Unlike Australian children of immigrants, children of immigrants in Germany have been shown to be particularly at risk of low educational attainment and to be generally underrepresented in Gymnasiums and higher education.

In the past decade a number of educational reforms have been implemented in all states, some of which were already underway before the PISA debate. Not all reforms were carried out in all states or at the same time, however most states have implemented a sub-set of the following reforms:

– An emphasis on learning rather than playing in preschool
– Flexible multi-grade reception phases in primary schools
– Introduction of foreign language teaching in primary school
– Standardised testing
– Focus on evaluation and quality management for schools
– Increased autonomy (mainly in profiling and budget planning) of individual schools
– Rewriting curricula with an emphasis on competencies
– Reform of the school structure (namely the abolition of the *Hauptschule*)
– Shorter duration of schooling (earlier school entry, earlier exit from *Gymnasium*)
– Introduction of the concept of literacy
– Increased efforts to promote German language proficiency of immigrant students
– Increasing the number of whole-day schools
– Enhanced science teaching, including an emphasis on science teaching in primary schools

Science education in Germany has received renewed interest in recent years (Möller et al. 2012). This is due in part to the results of PISA and TIMSS and in part in recognition of the need for a more widespread general scientific literacy. In 2009 the KMK issued a resolution recommending the enhancement of mathematics, science, technology and IT learning (KMK 2009). The KMK paper points to the importance of STEM education for the German economy particularly in view of an acute shortage of high-skilled labour in technical and science related fields. Beyond this the resolution also highlights the importance of STEM education for citizens to take informed decisions in a world increasingly influenced by scientific and technological innovations.

In recent years there have been efforts to increase the amount and quality of science teaching in all states from early science in Kindergarten to science education in primary and secondary school (KMK 2011). In 2011, the Freie Universitaet Berlin introduced a new science degree program for students of primary education called Integrated Sciences. This was the first program of its kind in Germany. Beyond formal education, science presently also enjoys increased popularity in general. Some studies suggested that relatively good results of German primary school children in international science assessment studies are due not to the quality of science teaching, but rather to activities outside of schools (Möller et al. 2012).

Compared to the results of secondary German students in PISA, German primary school children achieved relatively good results in TIMSS 2007 and 2011 (Wendt et al. 2012). However, in spite of the overall picture, researchers have pointed to a significant gender divide in science competency. Achievement levels also correlate significantly with the socio-economic status of students and children of immigrant background are overrepresented in the lowest competency group.

In primary schools in all states science is taught as part of *Sachunterricht*, a general subject comprising knowledge considered of relevance to young children with elements of social studies, science, history, citizen education and health care. *Sachunterricht* is usually taught by the 'home' teacher, who will in most cases have no special training in teaching science. Most primary teachers give priority to biology topics over topics relating to other sciences (Ramseger 2010).

While inquiry-based learning is generally encouraged, Ramseger (2010) has criticised hands-on activities with an emphasis on fun, which enjoy increasing popularity in science classrooms but which are often not connected to learning goals or accompanied by classroom explanatory discourse. As a result children are not able to grasp the scientific concepts involved and their experiences do not lead to the desired conceptual change (Ramseger 2010). Möller and others have advocated a constructivist approach with more scaffolding elements and structured learning sequences (Ewerhardy et al. 2012) and most recently, based on a meta-analysis of 61 books or articles on didactical research, Ramseger has presented 10 principles of good science teaching for primary teachers (Ramseger 2013).

German Science Curriculum and Assessment

Unlike for other subjects, there are no common nationwide standards for science teaching in primary school. However, the Society for Didactics of Sachunterricht (Gesellschaft für Didaktik des Sachunterrichts, in short GDSU) has issued a Perspectives Framework, which contains goals and competencies for teaching *Sachunterricht* from different perspectives (Gesellschaft für Didaktik des

Sachunterrichts 2013). The framework is organised according to five perspectives – social science, natural science, geography, history, and technology. Ideally, students should be encouraged to engage with a given phenomenon of interest and consider it from all the above perspectives, though in practice, this is rarely realised. Most states have used the Perspectives Framework as a guideline for their curricula. For the natural science perspective, the framework enlists five thinking, working and activity strategies: examining and understanding natural phenomena objectively, knowing and using scientific methods, deriving regularities from natural phenomena, deriving consequences for everyday life from acquired scientific knowledge, and reflecting upon and evaluating scientific learning (Gesellschaft für Didaktik des Sachunterrichts 2013). This also includes an understanding of the nature of science and the possibilities and limits of scientific knowledge. The framework recommends five topics: non-organic nature – properties of matters, changes of matter, and physical processes; living nature – plants, animals and categorisations, and development and living conditions of living things.

The joint curriculum of Berlin and Brandenburg is divided into seven broader topics: Getting to know oneself, Living together, Exploring natural phenomena, Discovering spaces, Understanding time and history, Comprehending technology, and Using media (Senatsverwaltung für Bildung, Jugend und Sport Berlin 2004). The Perspectives Framework as well as the Berlin-Brandenburg curriculum for *Sachunterricht* follow a constructivist approach to learning and emphasise a child-centred approach. At the same time students should also be introduced to scientific concepts of the subjects which will be taught independently from Grade 5, as outlined in the Perspectives Framework. While the curriculum states that topics are to be taught in an exemplary way, teachers complain that the curriculum contains too many topics.

As in Australia, teachers in Germany are free to decide on the methods of assessment, which can include written, oral or practical forms of assessment. While teachers may resort to written exams as in other subjects, different means, such as portfolios, science logs and presentations in class are also common in science classrooms. In Berlin, as in many other states in Germany, parents decide whether student performance is documented in grades or verbal descriptions on report cards for Grades 3 and 4 (Grades 2–4 in Brandenburg). Report cards are issued once or twice a year. In Berlin and Brandenburg integrated science (and for Brandenburg alternatively Physics and Biology) is taught as a regular subject 4 h per week in Grades 5 and 6 and is considered a major subject along with German, English and Mathematics.

School Governance and the Role of Parents

Schooling being compulsory and home-schooling explicitly forbidden, German parents are allocated substantial rights with regard to their children's schooling. Beyond information rights they can also influence the development of schools, choice of learning materials and teaching methods of their children's school to some extent and they use their presence on school boards and local and state committees to represent their interests. However, parents of high socio-economic status tend to be overrepresented in school committees and are generally better informed about their rights than parents of low socio-economic status (Sacher 2009).

Parent's expectations are high, while trust in the German education system has decreased particularly since the publications of the first PISA study, as the rising numbers of students enrolled at private schools suggest (Weiß 2011). Parents of immigrant background have been shown to have high aspirations but often have less knowledge of the education system and their choices and rights (Hawighorst 2009).

Teachers and Teacher Education

Prospective teachers study 4–5 years at university. Recently the system has been reformed in line with the EU Bologna agreement. Instead of passing the *Staatsexamen* students now have to complete a 3-year Bachelor's degree comprising discipline studies plus education studies, and then a Masters program in education, which is often of 1-year duration for primary teachers and 2 years for secondary teachers. Students take courses in general educational theory and in their chosen subject or subjects. Primary education students in Berlin choose one subject plus primary education consisting of courses in general primary education, German, Maths and *Sachunterricht* or Music and Art. Following this they have to complete 18 months of in-service training through an internship and pass another final exam.

Primary teachers are required to teach 28, 45-min lessons per week. In most schools there are few regular conferences and teachers mostly prepare lessons alone at home. According to a survey carried out in 2011/2012, 15 % of Berlin's and 18 % of Brandenburg's primary teachers had not enrolled in any professional training program during the past 2 years. On the other hand, 38 % of Berlin's and 56 % of Brandenburg's primary teachers had taken part in more than five programs over the past 2 years (Autorengruppe Bildungsberichterstattung 2014).

There is a marked predominance of female teachers in primary schools. Unlike teachers of secondary schools, primary teachers enjoy a positive image in society (Ricken 2007). However, salaries for primary teachers are considerably lower than those of secondary teachers.

In 2012/2013, 46 % of regularly employed teachers were above 50 years old (Autorengruppe Bildungsberichterstattung 2014). With a generation of teachers reaching retirement age and an increasing number of teachers opting for early retirement there is a nation-wide acute shortage of teachers, particularly for STEM subjects. Teachers are mostly employed as civil servants; however, Berlin has abolished this option.

Typical Science Classrooms

From Grade 1 to 4, science is taught as part of *Sachunterricht* and this usually takes place in the 'home' classroom. Science laboratories exist in some schools, but are mostly used for science teaching in Grades 5 and 6. Most classrooms have a blackboard at the front, near to the teacher's desk. On average, there are 23 boys and girls in each class in Berlin primary schools (Senatsverwaltung für Bildung, Jugend und Wissenschaft Berlin 2014). The teacher, who is usually the home teacher and also teaches most other subjects, will sometimes be assisted by an educator or a teacher for special needs. The students' desks are often arranged in squares, so that groups of children sit facing each other. Desks may also be arranged in rows, depending on the preference of the teacher. Each student has a shelf to store some material. Shoes are often left in the corridor and exchanged for slippers, though students rarely sit on the floor. German primary students typically have large satchels, which are filled with school books, copy books, writing material, a water bottle, snacks and often some toys. The students place these next to their desk and take them home at the end of the day. The classroom walls and windows are decorated with students' artefacts. Some classrooms will have plants, which are taken care of by the students. Hands-on activities with everyday materials are often part of science lessons and when the weather is favourable, teachers sometimes take the students outdoors. Many teachers resort to worksheets or workbooks, some will ask the students to produce a portfolio or keep a science log book. School books are available, but rarely used in *Sachunterricht*. Most classrooms have a computer with internet access in a corner. Interactive whiteboards are increasingly replacing blackboards. However, laptops and iPads are usually not found in German primary classrooms (Drossel et al. 2012). Students are frequently asked to research something using the internet or books, which will be brought in from the school or local library.

Taiwan

Located off the south-eastern coast of mainland China, at the western edge of the Pacific Ocean, Taiwan is a small island with an area of 36,000 km^2 and a population of 23 million. Less than 2 % of the population is indigenous and 98 % are descendants of immigrants from mainland China (70 % Holo, 15 % Hakka, and 13 % so-called 'mainlanders'). Taiwan has a history of colonisation being ruled by the Dutch, China (Ching Dynasty) and Japan. After 50 years of Japanese colonial rule (1895–1945), Taiwan was restored to Chinese rule at the end of World War II and then began to reflect a new tendency to transform itself gradually from a colony to a society governed by self-rule. Mandarin Chinese became the official language, Chinese culture related content was emphasised in the school curriculum, Japanese influences were purged and education played an important role in establishing a national identity and economic development.

Over the past 60 years, rising from island status to world presence, Taiwan has dealt successfully with its difficult international situation and managed to achieve remarkable feats in democratisation, education, and economic construction. Particularly, attributed to opening up the polity and society in late 1980s and introducing the direct electoral system in the 1990s, Taiwan has established itself as a modern democracy (Chen 2013). Also, through decades of hard work and sound economic management, Taiwan has created an economic miracle and transformed itself to an economic power that is a leading producer of high-tech goods, driven by sophisticated, capital- and technology-intensive industries and shifted toward developing the service sectors.

Structure of Schooling

The education system in Taiwan used to be a highly centralised, top-down system and the Ministry of Education played a major role in determining financing, policy and curriculum. Triggered by the democratisation, the liberation of the educational system and the diversification of curriculum have become the core issues in education reforms over the past 20 years. The current education system basically supports 22 years of study, including 2 years of preschool education, 6 years of primary education (ages 7–12), 3 years of junior high school, 3 years of senior high school, 4–7 years of college, and 1–7 years of graduate schools. Before 2014, compulsory schooling ended at the conclusion of junior high school in Grade 9 (age 15) and entrance to senior high school is based on national testing of Grade 9 students and these high stakes tests determine students' access to good high schools and in consequence create great pressures for students (Chiu and Chen 2012). Starting from 2014, compulsory education has been extended to 12 years and multi-track admission approaches to high school were adopted. The decades-old method of admitting junior high school students to senior high schools, through annually held joint entrance examinations, is now no longer the only option. Supposedly, it should ease the pressure of students and parents, but due to the competitiveness for getting into 'good' high schools, students' discontent and parents' doubts about the effectiveness and fairness of the multi-track admission program still remain high.

Educational Values and Philosophy

Education has been highly valued in Taiwanese society. Not only is it a key measure for self-realisation and social mobility, it is the foundation of national growth, and it is believed that the quality of education determines the competitiveness of Taiwan. Taiwan performs well in international testing programs such as TIMSS and PISA. Chiu and Chen explain that three factors play crucial roles in this success;

they are teachers' high expectations, parents' high expectations and competition between schools. These expectations may have their roots in "three traditional power hierarchies present in Taiwanese culture; teacher-student, male-female and parent-child. To some extent, these hierarchies may have derived from the teachings on Confucius (551–479 BC) and the hierarchies have endured in Modern Taiwanese society" (Baron and Chen 2012, p. 98). For example, in Taiwan, males are more likely to be expected by their parents to pursue scientific study and careers (Baron and Chen 2012).

Indeed, the success of its educational development over the past decades has contributed substantially to Taiwan's vibrant political and economic development. However, the traditional Chinese valuing of 'academic rationalism' has created a critical issue concerning test-driven and textbook-oriented pedagogical norms that many schools have maintained as part of their goal to press for the intellectual growth of students in the academic courses (Chen 2013). In Taiwan, parents expect children to have a career with high social status and a good salary. Therefore, parents are eager to ensure their children's academic success even in primary schooling. With the social norm of competitiveness; after school, students are often sent by their parents to private cram schools to improve their school performance. These private institutions tend to provide courses like English and mathematics with some offering courses that focus on science and technology. Confronted with these long unsolved issues, more and more progressive parents and educators advocate new ways of de-centralised schooling that encourage teachers' autonomy and parents' choice; develop students' talents and abilities; and, support teaching and learning for social justice.

School Governance and the Role of Parents

Recognising the importance of effective involvement and management with regard to pertinent government as well as parent expectations, most schools work very closely with local government and the community to incorporate various resources to strengthen their instructional environments for learning. From 2006, parents have a legal right to participate in school affairs and to cooperate with teachers to improve their children's education. Since then, parents have been engaged with school activities like school festivals, safety and security, environmental maintenance, and various volunteering work. In terms of science education, parents with a professional career in science, especially those teaching in universities are vigorously involved in supporting science teaching and learning, as well as extended activities like science fairs. As science at primary schools is often taught by specialist science teachers, only parents with a background or career in science tend to interact with science teachers in the support of science teaching.

Science Curriculum and Assessment

The National Science Council (now The Ministry of Science and Technology) is one of the most important of the academic institutions which promote science education and research in Taiwan. In 2003, the Ministry of Education and the National Science Council collaboratively developed the *White Paper for Science Education*, which identified missions for science education for the short term and long term (Ministry of Education and National Science Council 2003). The White paper also suggested that, at the level of primary education, the standards of science education should be established so that the goals, curriculum, teaching, assessment and policies in relation to science education would be consistent with each other. Moreover, science teachers' teaching knowledge and skills should be advanced (Chiu 2007).

The current curriculum guidelines for primary and junior high school state that the main goals of the science and technology learning area are as follows (Ministry of Education 2008):

1. To cultivate an interest in and a passion for science inquiry and habits of active learning.
2. To acquire methods of inquiry and a basic competence in learning science and technology and to be able to apply one's learning to daily life.
3. To cultivate a loving environment, to treasure resources, and to respect life.
4. To cultivate competence in communication, teamwork, and getting along harmoniously.
5. To cultivate independent thinking and problem solving and stimulate their potential.
6. To be aware of and explore the interactive relation between humans and technology.

Teachers are encouraged to adopt multiple teaching strategies such as lectures, experiments, problem-solving, discussion, and teamwork. They should provide students with various learning resources and take into account the natural environment within and beyond schools. Apart from the regular classroom work, teachers should urge students to undertake activities like designing experiments for science fairs, writing reports after visiting science museums and making good use of website information. Multimedia and the Internet should also be used to help teaching. As for assessment, teachers should combine formative assessment with summative assessment, and adopt dynamic assessment and portfolio assessment along with paper-and-pencil tests (Ministry of Education 2008). Chiu (2007) explains that most teachers rely on textbooks in their teaching. The textbook market is highly competitive and publishers provide teachers with comprehensive digital resources such as CDs, PowerPoints, teaching materials and sample test items.

As mentioned earlier, Taiwanese schooling is characterised by two features that are historical artefacts of the formerly strongly centralised and government controlled education system; these are the dependence on textbooks in teaching and the use of high stakes assessment to determine academic progression. Government sanctioned textbooks define the curriculum to be covered and the content that will be assessed through testing. Given the extensive content in the curriculum and textbooks that will be tested, teachers need to cover all the content resulting in teaching which is fast-paced. Also, paper-and-pencil tests play a major role in evaluating students' school performance. In view of this, how to assess students' inquiry skills in addition to mastery of the content is a challenge for science teachers and educators (Chiu and Chen 2012).

Pressed by various civil education groups urging for educational changes, and combining the recommendations of the *White Paper for Science Education*, there have been serious reform efforts for the improvement of science curriculum and assessment. Chiu (2007) summarised the curriculum reform agenda quite well:

> … moving from a national need to societal and personal needs; from standards to guidelines; from a national version of textbooks to multiple versions of textbooks; from elite education to general disciplines; from a content orientation to cultivating competencies; from centralization to decentralization; and from an academic rationalism approach to a personal relevance and social relevance approach. (pp. 307–308)

Teachers and Teacher Education

In order to guarantee a good quality of education, teachers in public primary schools are offered reasonable working conditions. Their salaries are higher than the average per capita income in Taiwan and they have pensions after retirement. From this point of view, the social status of teachers is relatively high in Taiwan. In 1994, the Normal Education Act was modified and renamed the Teacher Education Law. Since then, the teacher cultivation policy has changed from one that trains teachers in a planned manner with graduates assigned to designated schools to one that selects individuals through diverse channels with some having to pay for their normal education. The highly controlled system of teachers colleges training primary teachers and normal universities training high school teachers has been deregulated and all universities are able to establish their own teacher education programs which are approved by a central regulating authority. Further, these teacher education institutions are also responsible for providing in-service training and guidance for local education practitioners. This system has now created a large over-supply of trained teachers (Chen 2013).

Basically, specialised courses are designed to train teachers who are able to teach the subjects comprising the curriculum. Regular and education practical training courses are designed to develop in teachers a humanistic disposition and concern, and general knowledge so that they are willing to devote themselves to cultivating a quality next generation (Ministry of Education 2006a).

It is noticeable that, in 2011, only one-third of the fourth grade students were taught by teachers who had a major in education and science (31 %) (Martin et al. 2012). A survey of Taiwanese primary school teachers conducted by Wu et al. (2011) revealed that one-quarter of primary school teachers had a major in mathematics/science and the average teaching experience for primary school teachers was 12.37 years.

The Ministry of Education provides teachers with plenty of opportunities for professional development. They mainly include (Ministry of Education 2006b):

1. Regional teacher in-service education centres and websites: The Ministry subsidises regional teacher in-service education centres and websites to offer an experience exchange channel among teachers.
2. Teacher in-service education credit classes and degree classes: Teachers are generally expected to raise their educational background to a masters degree level. According to a survey conducted by the Ministry of Education, there are more than 35 % of primary teachers with a masters degree.
3. Workshops and conferences held by teacher education universities.

In Taiwan, primary science education is taught by specialist science teachers, especially at large schools. At middle sized and small schools, science lessons are given by teachers who are not trained to be science teachers. This is one of the main concerns regarding primary science education.

On average, in 2011, Taiwan devoted 2.3 h per week on science teaching for students of the fourth grade (Martin et al. 2012). Also, nearly one-third of the fourth grade students (27 %) had "very collaborative" teachers having interactions with other teachers in order to "discuss how to teach a particular topic", to "collaborate in planning and preparing instructional materials", to "share what they have learnt about their teaching experiences", to "visit another classroom to learn more about teaching" and to "work together to try out new ideas" (Martin et al. 2012, p. 365).

Typical Science Classrooms

In Taiwan most primary schools have science classroom/s, and some schools even have a purpose built 'future classroom' equipped with advanced high-tech facilities. Basically, at least one science room or a science laboratory is set up for the purpose of science education at each primary school. According to a recent survey, 89 % of Taiwanese students at the fourth grade could have access to a science laboratory. In general, private schools attended by students with advantaged home backgrounds can provide better school resources for teaching science. As for public schools, in rural areas or small towns, science rooms or laboratories are often poorly equipped with facilities for experiments and teaching. Despite this, it varies from school to school. Schools with science teachers who are devoted to science education often can provide sufficient facilities and equipment.

Discussion and Conclusions

Classrooms and schools are embedded in complex and layered social and cultural contexts that influence the development of students, teachers and schools. Each of the three countries studied has distinct cultural and historical factors that frame the ways in which education systems, schools and classrooms operate. Differences in these historical, cultural and philosophical factors help explain the differences observed in the ways that science is taught and how teachers create rich opportunities for higher order thinking and reasoning.

The philosophical principles and values framing education in Australia, Germany and Taiwan have their roots in each country's history and values. As a country developed through waves of migration, Australian values reflect beliefs in egalitarianism, a fair go and opportunity for all. Government schools are most commonly secular, co-educational, non-selective and comprehensive catering for students of the full range of abilities and interests. Those parents desiring a religiously-based education for their children will send their children to fee-paying non-government schools operated by various religious denominations, most commonly Catholic, Anglican or Uniting Church schools. Most primary teachers operate classrooms that are democratic and highly participatory so that many students make some contributions to classroom discussions in each lesson. Students have free and non-competitive access to their local secondary school so that there is no competition for high grades in primary schools. Parents act as supporters of their local school, raising funds for facilities and equipment, organising social functions and some parents assist in classrooms listening to children read. Parents have little role in school governance or policy formulation as policy and pedagogy are considered the preserve of the professionals.

German education is strongly influenced by democratic values and the philosophical principle of *Bildung*. Parents have the right to engage with school policy development and may challenge teachers on matters such as assessment policy. Primary schools and teachers highly value the development of the individual as an educated and self-directed person who can contribute positively to society. The thoughts, ideas and interests of the individual are valued, and primary curricula explicitly state that these should be taken into consideration in lesson development and teaching. This was reflected in the German cases observed in this study, a small number of students were often allowed to present extended and reasoned arguments and explanations to the class. In view of the heterogeneity of students in primary schools due to demographical changes, integration of children with special needs and other factors as well as related reforms (multi-grade classes, inclusion) German primary teachers are increasingly expected to develop individualised learning opportunities adapted to the specific needs of each child. In multi-grade classes students will often work on different tasks individually or in small groups. While outcome-oriented curricula are designed to ensure that all students reach the same goals, to date no nation-wide standards have been developed for *Sachunterricht* and science teaching. Unlike Maths or German for which all schools have to participate in yearly standardised assessments, no such tests have been developed for *Sachunterricht*. Thus there is less pressure on teachers to reach specific learning goals in a given time.

Confucian and other cultural values of respect for books, knowledge, adults, teachers, hard work and fairness in competition for advancement have strongly influenced the operation of the Taiwanese education system, schools and the teaching and learning of science. Unlike Australia and Germany with their federal political and educational structures, Taiwan has a national and systematic approach to curriculum, curriculum resources and assessment of learning. Fairness in competition for good grades is ensured by students completing tests. Teaching is a respected profession and students show respect for their parents and teachers by working hard and striving for good grades which are required for admission into good secondary schools. Many parents support their children and school by working as volunteers in a wide range of capacities.

The approaches to assessment of students' learning appear to be influenced by cultural values, philosophical principles, the degree of autonomy of teachers and the degree of competition for entry into good secondary schools. Fairness in the intense competition for good grades in Taiwan is ensured by assessment being largely based on tests. In Germany, where there is emerging competition for good grades, assessment is based on a combination of tests and other assignments, however, in some schools there may be no tests. Australian teachers have a high degree of autonomy over their practice so that assessment varies strongly between one teacher and another and given that there is little competition for grades with non-competitive entry to comprehensive secondary schools, testing is rarely used by classroom teachers. Assessment is often based on classwork and teachers' anecdotal records of students' learning outcomes.

The structure of political systems has influenced the structure of education systems and the coherence of curriculum. Taiwan has a unified national political and education system which has resulted in a coherent national curriculum with nationally approved text books and curriculum resources that are used in every school and classroom. The federal political systems of Australia and Germany have led to curriculum differences between states and these differences are diminishing in Australia as a national curriculum is gradually being implemented across all states. Despite these different curriculum structures, the science curricula of all three countries focus on similar science disciplines and learning outcomes. The amount and level of curriculum content, however, does differ between countries. There appears to be far more content specified in the Taiwanese curriculum than in Australia and Germany and classroom observations reveal that this engenders a faster-paced style of teaching in Taiwan compared to the slower-paced style of Australian and German teachers.

The time made available for teaching science appears to be influenced by the practices of employing specialist or generalist teachers of science and the philosophy of teaching science as a separate subject or integrating science with other subjects in the curriculum. With the common practice of specialist teachers teaching each subject in Taiwanese primary schools there is a timetable which determines time allocation to the teaching of each subject. This results in uniformity between classrooms and schools in that science is allocated three 40-min lessons each week in Grade 4. In Australia with a high level of teacher autonomy, the common practice of a generalist teacher teaching science integrated with other subjects, it is difficult to determine how much time is allocated to science and there is great variation between classrooms. The most reliable estimates indicate that on average, Grade 4 students receive 42 min of science instruction per week (Angus et al. 2007). There is a similar situation in Germany, where at Grade 4, science is taught as part of the *Sachunterricht* set of subjects making it very difficult to determine how much time is allocated to the study of science.

The quality of teaching is dependent on the quality of teachers. Effective teaching of science requires a rich body of subject specific pedagogical content knowledge (PCK) (Berry et al. 2015). Able teacher education candidates, a high quality pre-service teacher education and on-going professional learning are necessary to build this rich PCK. The most able school graduates are attracted to teacher education in Taiwan as teaching is a respected profession, and because good salaries and pension schemes are provided. Students need good grades to enter teacher education in Germany as primary teaching is an attractive and secure occupation. Teaching is a less prestigious occupation in Australia compared with Germany and particularly Taiwan, and consequently the most academically able school graduates are rarely attracted to teaching. In all three countries teachers receive a minimum of 4 years of university level pre-service education; however, there are differences in access to science-specific professional learning once in the workforce. In Taiwan, all specialist science teachers in a county are given the same half day each week free of teaching so that they can meet, attend professional learning sessions and work collaboratively. German and Australian teachers of primary science have less opportunity to access collaborative science-specific professional learning. In Australia, science professional learning is sporadic and dependent on particular state-based initiatives and is most commonly based on *Primary Connections*.

Developing an understanding of science teaching and learning practices requires classroom-video researchers to interpret what they see in terms of the historical, social and cultural contexts of the country. The analysis of the Australian, German and Taiwanese education systems and cultures draws attention to the important influences of social and philosophical values, education policies and curriculum frameworks; and the expectations of parents, schools and other teachers on the practice of teachers. When observing classrooms in a country other than one's own and when making comparisons between countries, great caution needs to be exercised to ensure that interpretations are informed by local cultural factors and that interpretations are not generalised beyond the classrooms observed.

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Part II
Case Study Analyses

Part II comprises six chapters which report on analyses of the case studies collected in Australia, Germany and Taiwan. The cross-cultural analyses focus on the physical learning environments of classrooms, the use of different instructional settings, inquiry teaching and learning, classroom discourse, reasoning and use of embodied strategies.

Chapter 3
Physical Learning Environments for Science Education: An Ethnographic Field Study of Primary Classrooms in Australia, Germany and Taiwan

Peter Hubber and Jörg Ramseger

Introduction

In recent years many attempts have been made in designing evidence-based instruments for the evaluation of learning environments. One promising approach, for example, can be seen in the *Classroom Arrangement Rating Scale* by Sanoff (2001). But as Cleveland and Fisher state in a critical review of the literature on the evaluation of physical learning environments, approaches to evaluate "the effectiveness of physical learning environments in supporting pedagogical activities are in their infancy and require further development" (Cleveland and Fisher 2014, p. 24). These researchers argue that the research literature focuses "…predominantly on the physical features of the physical environment itself, rather than the alignment between spaces and desired educational practices, activities and behaviours". Insights into this alignment can be expected from the E21LE study (*Evaluating 21st Century Learning Environments*) at the University of Melbourne; a study funded by the Australian Research Council that started in 2013 and is expected to deliver major outcomes in 2016.

Until then, we return to pedagogical studies that refer more to the experiences of teachers and pedagogical experts than to empirical data. The consistent and overwhelming evidence of this type of research, that has investigated the relationship between students' achievements and the quality of the classroom learning environment, is that the classroom environment strongly influences students' learning outcomes

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(Cleveland and Fischer 2014; Dreier et al. 1999; Fraser 2012; Kroner 1994; Rittelmeyer 1990, 1994). The learning environment does not just constitute a physical space but also consists of a variety of tools and sources of information, the relationships between students and students and the teacher, as well as expectations and norms of learning behaviour (Puteh et al. 2015). The essence of a learning environment is the interaction that occurs between individuals, groups and the setting within which they operate. Consequently Heft (1988) has suggested "that environmental features should be described in terms of the developmental activities they encourage" (Dudek 2013, p. 97).

The physical aspect of a learning space reflects ideas, values, behaviours and culture which are expected of such a space. Certain behaviours and practices can form part of the routines of use of the space by the teacher. Essentially, once taught, routines are daily activities that students are able to complete with little or no teacher assistance, which accomplishes two objectives: (1) students have more opportunity to learn, and (2) teachers can devote more time to instruction (Colvin and Lazar 1995).

According to Roskos and Neuman (2011, p. 111) the classroom space "should accommodate multiple configurations for large and small groups, for triads, pairs, and individuals to talk, listen, write, read, play, and learn." Puteh et al. (2015) believe that it is important that the physical classroom is one that is stimulating and conducive to the creation of a comfortable teaching and learning environment. A conducive environment "can help increase intellectual activities, encourage friendship, cooperation and support among the students, and at the same time, promote learning, student growth and development" (p. 237).

Classrooms therefore serve not only as accommodation for the students, they compel them to come together as a learning group under the leadership of a teacher providing them with direction. They also have a marked influence on opportunities for the development of students and their young intellects in the school context.

Bendix et al. (2015) recently pointed out that school architecture, room design and the use of rooms from an ethnographic point of view symbolise the way teaching and learning are seen by educators, administrators and architects. Thus school buildings and classrooms are representations of the image of learning at school and the culture of schooling that is prevalent at a certain time in a certain culture (compare Figs. 3.1 and 3.2).

> This is associated with a research tradition in cultural anthropology which aims to get to grips with the experienced and ethnographically depictable reality of school. School is viewed as an entity, as a construction that is determined partly by social and political contexts and conditions, but which is also influenced by interactions with various actors who have agreed upon particular rules and norms and follow certain practices in securing the intricately constructed artefact they have built. School is, moreover, an object which is realised in both concrete and imagined spaces, being influenced by them and in turn working with and elaborating them (Bendix et al. 2015, p. 83. Translation by the authors of this book).

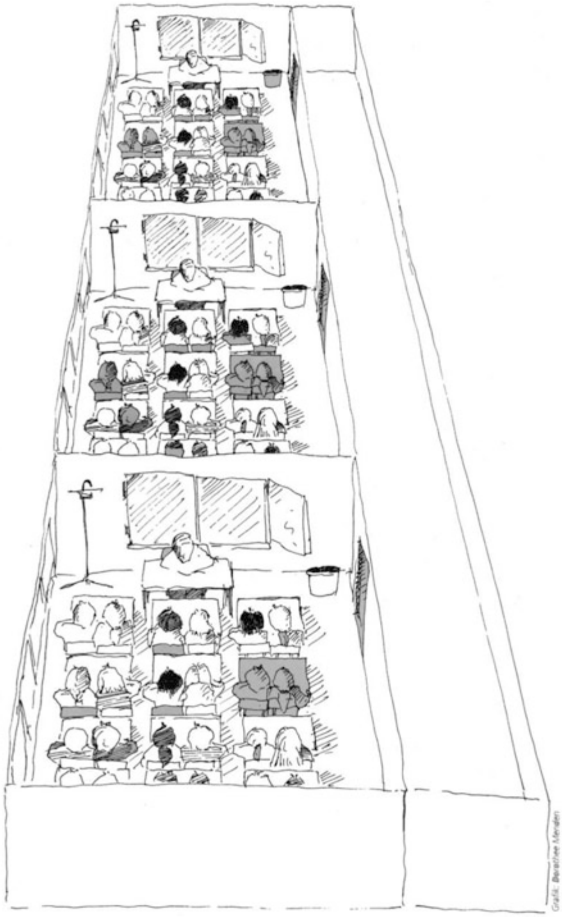

Fig. 3.1 Classrooms represent the way learning is viewed in a certain culture at a certain time (Illustration: 'Lernen im Quadrat' (Learning in a square) by Dorothee Menden. Retrieved from Dreier et al. 1999, p. 20. By courtesy of Grundschulverband e.V., Frankfurt/M)

Theoretical Framing of Our Study

When thinking of science teaching, most people who have had the benefit of advanced school education probably think first of school laboratories with fixed tables with water and gas taps and electricity sockets, of technical equipment and measuring instruments. Some of the primary schools we saw in Taiwan were indeed equipped like this. Most primary schools in Australia and Germany do not have science laboratories of this kind. Here science lessons are generally conducted in the standard home room where several subjects are taught.

It seems easy to picture what modern student laboratories should look like. Although it would seem the obvious thing for science teaching generally to have recourse to laboratory equipment in science laboratories, in this Chapter we shall dare to take an entirely different perspective on science in the primary school; we

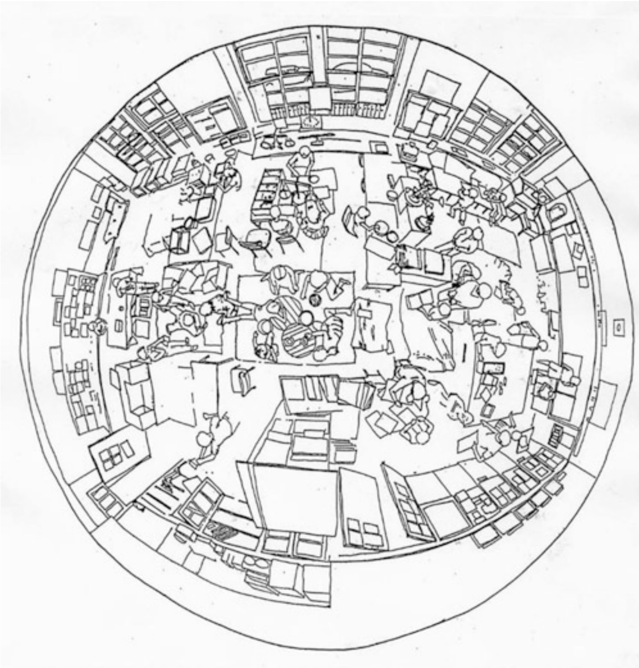

Fig. 3.2 Classrooms represent the way learning is viewed in a certain culture at a certain time (Illustration by George Vlastos (Taylor and Vlastos 1983, p. 43). By courtesy of School Zone Inc., Corrales, New Mexico)

shall risk a retrospective view to see whether from historical concepts of room design for primary school teaching we may be able to glean criteria for the design of contemporary learning environments in the twenty-first century. We opt, therefore, for a cultural-historical perspective in assessing the room designs we have seen in EQUALPRIME schools, on the assumption that some of the key principles of effective pedagogics can boast long-term applicability, not necessarily becoming obsolete with changing times. Moreover, a retrospective look at what are now almost historical conceptions of room design will help to carve out more precisely the new elements of room concepts for science pedagogies in the twenty-first century.

In the following discussion we concentrate on three polished theoretical concepts of room design in twentieth-century European early learning contexts which have explicitly set out the connection between room design and the acquisition of knowledge. At least in European education, but to some extent also in Asia, America and Australia, they have attracted special professional interest and in many cases have been implemented in practice. Occupation with these traditional theoretical conceptions provides us with questions with which we can analyse current room designs in the schools of the EQUALPRIME project.

The 'Prepared Environment' (Maria Montessori)

The physician, educator and anthropologist Maria Montessori (1870–1952) developed her concept of the 'prepared environment' in 1907, in the *Casa dei Bambini* or 'Children's House', a pre-school for 3 to 6- year olds in the working-class district of San Lorenzo in Rome. The demand she made on the educational environment provided for the students is far-reaching and is marked by an idealism that sounds rather alien to contemporary ears:

> Scientific observation has established that education is not what the teacher gives; education is a natural process spontaneously carried out by the human individual, and is acquired not by listening to words but by experiences upon the environment. The task of the teacher becomes that of preparing a series of motives of cultural activity, spread over a specially prepared environment, and then refraining from obtrusive interference. Human teachers can only help the great work that is being done, as servants help the master. Doing so, they will be witnesses to the unfolding of the human soul and to the rising of a New Man who will not be a victim of events, but will have the clarity of vision to direct and shape the future of human society (Montessori 1974, p. 3. First published in 1946).

The 'prepared environment' is one of the main principles of Montessori pedagogy. 'Prepared' refers to three aspects of the environment:

1. The first and most important aspect of the learning environment is the teacher whose main task is to prepare an appropriate environment for the specific needs of the children in his or her class.
2. The second aspect is the room: its architecture, the design of the materials and the way things are offered to and used by the children.
3. The third aspect is the preparation of the content by the teacher.

Below we concentrate on the second aspect, i.e. the physical environment in which teaching and learning take place.

> When we speak of environment we include the whole assemblage of things from which the child is free to choose for using just as he pleases, that is to say, in conformity with his inclinations and his needs for actions. The teacher does nothing beyond helping him at first to get his bearings among so many different things and to find out the precise use of them; that is to say, she initiates him into the ordered and active life of the environment … Educational influence is diffused through all the surroundings, and persons, children and teacher, come to take their share in it (Montessori 2004, p. 83).

Montessori constantly developed material and made it available to the children to have sensory, practical, and intellectual experiences on their own, largely independently of the teacher. She built small, light tables, and chairs which the children could move around and re-arrange as appropriate for each activity. The material she constructed was designed to promote disciplinary and cross-disciplinary skills, largely through self-teaching, allowing students to take simple and complex learning steps at their own pace. The golden beads materials for mathematics are world-famous and still in use in thousands of kindergartens and schools around the world.

Nothing is left to chance: the materials are cleverly designed, aesthetically attractive, stable, and can generally be used only for one purpose and can help only in reaching a single, precise, previously set learning objective. The teacher and his or her teaching style are present in the materials, which in turn are housed and available in their special logical place in the classroom. It is the teacher's job to ensure this order and prepare the classroom in such a way that the students can take the learning steps appropriate for their individual development largely on their own as they get to grips with the materials. In addition, disruptive and distracting influences are kept at bay as far as possible.

In a Montessori school the children move around freely in the classroom for large parts of the day, choose their own tasks and work individually or in small groups; often squatting on rugs on the floor. Surprisingly, in this position, they also conduct studies in science. The prepared environment and the materials provided have a 'disciplining' effect, replacing the direct supervision of the children's behaviour by the teacher. The teacher's authority is equally present and reflected in the layout of the room and the materials.

In relation to science teaching in the primary school, some analytical questions may be derived from Maria Montessori's essay on the 'prepared environment' which facilitates a more precise understanding and description of the spatial concept of any primary school; even nowadays:

1. Does the classroom represent a 'prepared environment' in such a way that the furniture and the materials available to the children are placed purposefully and can readily be used for predetermined purposes?
2. Do the materials and the physical environment provide a stimulus for ordering things in a constructivist sense which the child can take on board and internalise?
3. Do the students have the freedom, with the aid of the materials provided, to make the world their own for extensive phases of their development?

The 'School as a Workshop' (Célestin Freinet)

Célestin Freinet (1896–1966) was a primary school teacher and educational reformer from southern France and in the first half of the twentieth century was the founder of what initially was a national teachers' movement for the construction of a 'new school' which, although it never became quite as popular as Montessori pedagogy, for example, found worldwide dissemination under the title *Fédération Internationale des Mouvements de l'École Moderne* (*F.I.M.E.M.*). The F.I.M.E.M. is still active today (cf. http://www.fimem-freinet.org/fr).

Freinet (1978, 1980) regards the school class as a cooperative in which students make their environment their own by free exploration, largely unaided. Freinet pedagogy comprises a number of pedagogic techniques and principles, the most important of which are 'free expression' (*expression libre*) and 'experimental probing' (*tâtonnement experimental*), a form of inquiry based learning in small groups including a certain amount of trial-and-error while trying to resolve questions about nature. In Freinet's pedagogy, everything that happens pedagogically serves to strengthen the children's capacity for expression, giving them a voice. Language, the arts, mathematics, and also scientific discoveries by the children are recorded in 'free texts' in which the children's view of the world and their investigations are documented and published. In earlier times this purpose was served by the mechanical printing press which made Freinet famous; these days its place has been taken by the internet-connected computer, on which the children conduct their own research, before summarising their study in reports and printed documents which are subsequently sent to correspondence partners in other cities or published in class newspapers and self-produced books.

Freinet pedagogy is primarily pedagogy by work. For Freinet, work is always a creative activity and always concrete. Freinet takes it for granted that all children really want to work in a creative sense, thereby producing meaning. The traditional school, for Freinet, suppresses this meaning of work by setting the children tasks they did not ask for. In the Freinet class the children are allowed to work hard because they are free to follow up their own questions and look for answers to their questions about the world.

> Practical work and intellectual work go back to the same acting mechanism in the course of experimental probing. The sculptor and the researcher and the child in the Freinet class then pursue the same activity: from an irregular shape (a question, a problem, a task), they sculpt a clear figure, creating new meaning and new significance through their own efforts – for themselves and for others (Ramseger 1991, p. 119).

If the internal logic of the child's learning process is analogous to the activity of an artisan, it is consistent to set out the classroom as a workshop too. Freinet classes look very much like twentieth-century workshops. What immediately strikes one when visiting a Freinet class is the wealth of materials:

> There are things standing around everywhere – products of the children's work, written work in particular, are spread out, displayed, hung up everywhere. Work sheets (*fichiers de travail*) and materials are stored by topic in special zones of the room (*ateliers*) and encourage the students to discover and work with them. A good deal of wood, paper, simple instruments and items for use. Hands-on things. Everything always looks a bit overloaded. But the varnish and gloss of modern teaching materials and office equipment are missing. Nonetheless clear principles of order are discernible …. The dominant feel is of the lovable but at the same time strict character of an old-fashioned craftsman's workshop (Ramseger 1991, p. 113).

The children follow up questions they have chosen themselves, with information which they gather from the books available to them and on exploratory walks into the neighbourhood to places where things are really happening: at a blacksmith's workshop, at the bakery, the mayor's office, the police station or the post office, but also with experts like artists or scientists. Learning occurs especially in the forms of research and reporting.

To some degree Freinet was a technology enthusiast, being very progressive for his time in relation to the use of modern media. Correspondingly, modern Freinet classrooms also contain computers which facilitate research work but cannot provide the authenticity of original encounters with reality.

If we adopt some of the key pointers of Freinet pedagogy for the design of learning rooms for science teaching, we could tease out the following analytical questions for today's schools:

4. Is there an adequate variety of materials that stimulates the children and to which they can help themselves in bringing their questions to an answer?
5. Are there sufficient possibilities in the classroom for productive work, including work zones, wet zones, research and publication tools?
6. Can the children work seriously in their investigations, as grown-up artisans, artists or scientist would do? Or do they simply do 'assignments' that teachers have given them?

The Room as 'Third Educator' (Reggio Pedagogy)

The Reggio approach, a contemporary teaching approach in early childhood education, uses the environment as the 'third teacher' or, literally translated, as a 'third educator' (Strong-Wilson and Ellis 2007; Torquati and Ernst 2013). According to this approach the classmates are the first educators and the teacher is the second one.

This is a concept of elementary pedagogics which takes even small children as active constructors of reality. It was developed in the late 1960s in the town of Reggio Emilia in northern Italy. By means of a wealth of aesthetic stimuli in their culturally sophisticated environment the children should learn to understand themselves, even in their earliest years, as shapers of the world. Art, culture, literature and science are not separate disciplines. Rather, artistic, literary and scientific forms of acquisition and production complement each other in the systematic exploration of the world by the children themselves. One of the most prominent advocates of Reggio pedagogics, Loris Malaguzzi, writes: "Rooms serve the goal of rediscovering the awe and the magic of everyday phenomena. Our facilities are, above all, workshops in which children examine and investigate the world" (Malaguzzi, retrieved from Ullrich and Brockschnieder 2001, p. 65).

Torquati and Ernst (2013) describe Reggio crèches:

> Spaces are carefully and intentionally planned within the Reggio Emilia schools to be welcoming, to reflect the culture of the children and the community, to make visible the teaching and learning, to support social interactions, to be appropriate for children at different ages and levels of development, to afford opportunities for active learning, and to communicate the values and opportunities for learning within. Environments and spaces are viewed as flexible, active, and responsive to the children and teachers who use them, as "elements that condition and are conditioned by the actions of children and adults who are active in it" (Gandini 1998, p. 177)….A strong sense of place and culture are encouraged as investigations extend outward into the city and culture flows inward as families, children, and visitors bring cultural artefacts and meaningful treasures into the school. (p. 191)

So the environment is intentionally and carefully planned to enhance collaboration and social interaction, which are key principles of the Reggio philosophy.

Teachers organise environments to provoke and encourage exploration and problem solving. In this way the environment directs the learning process naturally (Cadwell 1997; for a critical examination of the Reggio principles see Hall et al. 2010).

If we apply the principles of Reggio pedagogy to contemporary primary science teaching, further questions emerge for the assessment of real learning environments:

7. Do the rooms serve the objective of rediscovering the awe and magic of everyday phenomena?
8. Do the students receive rich stimuli for learning in the classroom which help them understand the context of nature, culture and social life?
9. Do the students not only have opportunity for rational analysis of the environment with the traditional tools of science and mathematics, but also gain an insight into the historical, cultural and local situation in which they live and in which the scientific knowledge gained becomes effective in practice?

Case Study 1: Mr Roberts' Room (Australia)

The case described below refers to an Australian government metropolitan school that involved a teacher, named Mr Roberts, who taught a class of Grade 4 students the topic of forces. The school in which Mr Roberts teaches is an inner city government funded elementary school catering for 415 students between the ages of 5 and 12-years old. The cohort of students is ethnically diverse and includes recently arrived refugees; 39 % of the students have a language background other than English. The socio-economic background of the students and their families is mixed. Results from national literacy and numeracy tests indicate that the school is above the national average. The school's mission is to promote the social, emotional and academic growth of all students. The staff want the children to be able to make informed, responsible choices. There are some special curriculum foci including Arts, Italian language courses, Physical Education and Science. The school also offers extensive instrumental music programs.

Mr Roberts had the role of science specialist at his school. He was the only science specialist and taught each class in the school one 60-min lesson of science each week in a room dedicated to the teaching of science. Mr Roberts does not have a science degree but has a strong interest in the area of science and technology. Apart from his science teaching Mr Roberts ran extra-curricular science and technology activities at the school. Two such activities involved teams of students participating in state-wide school programs such as a Solar-boat Challenge and the Royal Automobile Club of Victoria Energy Challenge. Teams would design and construct a vehicle, such as a solar boat or recumbent bicycle, and compete with other school teams in the state-wide competitions.

Fig. 3.3 Mr Roberts' science classroom: A workshop for inquiry learning

The contents of the classroom in which Mr Roberts teaches were purposefully designed by Mr Roberts to reflect his philosophy of teaching, evident in the following quote, that it is important to challenge the students with engaging and enjoyable tasks.

> You've got to challenge them in their learning and I work from another premise. I find it really hard to teach a child if they're not happy. So if you've got them happy and you've got them engaged, I've got a chance. If I haven't got them engaged, and they're dead bored, or they're unhappy, my chances are limited. So it doesn't have to be fun but it has to be such that they're enjoying it. (Mr Roberts, Teacher-interview)

The classroom had a large open carpeted space at the front of the room and two sets of tables with chairs for 12 children in each set at the back of the room. All the students could sit comfortably around the large tables. Mr Roberts purposefully decorated the room with a wide range of representations of science (Figs. 3.3 and 3.4).

Upon entering the room one had the feeling of entering a science museum or exploratorium with a vast array of scientific artefacts to pique one's interest and engagement in science. Each wall had several charts on different science themes and topics. On the benches were instruments such as microscopes, telescopes, electrical meters and weighing machines. There was a myriad of animal specimens that included insects, animal bones, a crocodile head sticking out from the wall and a large turtle. Hanging from the ceiling was a large eagle's nest and solar boat models used in the previous year's Solar boat Challenge. There were physical models such as an astronomical Sun-Earth-Moon model, a Globe, several bones and skeletons, an electric motor, a body torso, and a model of a human brain. The room also had a terrarium and an aquarium. Contained within the open shelves were science materials, such as Lego technic kits, that were used by the students. The room also

Fig. 3.4 All materials are ready for the students to use

contained several computers with a printer, an electronic whiteboard and a ‘wet’ area with a sink and taps as well as a workbench with vices at each end.

The classroom setting, consisting of the physical space and equipment, facilitated Mr Roberts’ inquiry-based teaching approach adopted in the teaching of forces (details about his approach can be found in Chap. 10). The large open carpeted space at the front of the room was used in multiple ways by Mr Roberts and his students. Upon entering the room the students were not expected to sit down on chairs at the large tables but could move freely around, facilitated by the open spaces, engaging with the scientific artefacts in the few minutes before the lesson began. The lessons always began with a class discussion held in the open carpeted space.

Mr Roberts established the routine of engaging with the students in a class discussion as they sat on the floor, always at the beginning and the end of the lesson and at other times during the lesson (Fig. 3.5). Such a practice is often seen in Australian primary classrooms where teachers consider “time on the carpet in broadly constructivist terms, allowing them to engage interactively with the children and facilitate their learning” (Woolner et al. 2012, p. 52).

Mr Roberts often used the affordances of the carpeted space to come down to the level of the student by sitting among them (Fig. 3.5). The close proximity to the students gave Mr Roberts good insights into their thinking not only from the verbal responses they would give to his questions but their facial expressions as well. Mr Roberts commented:

> It is, because it’s me looking for their eyes. It’s me looking all the time. I wouldn’t get a piece of paper and say what did you learn today and you look at the bit of paper, I look for their eyes. I’m looking for the feedback from there, and the only way I’m going to get the feedback from them, was talk to them. (Mr Roberts, Teacher-interview)

Fig. 3.5 Mr Roberts' use of carpet space for class discussion

Mr Roberts employed the carpet space discussion at the beginning of the lesson to review the key ideas developed from the previous lesson and also to introduce the activities for the lesson. For each lesson in the forces teaching sequence students undertook at least one practical activity that centred on resolving some question or challenge raised in the discussion. Student activities generated by the discussions included the following:

- Mr Roberts showed the students a puppet and demonstrated the actions of push and pull as useful terms in understanding the concept of force. Each student was then given a lump of plasticine to sculpt into a shape of their choosing using the actions of pushing and pulling.
- In exploring ideas about gravity and air resistance Mr Roberts initially showed the students two sheets of paper and in class discussion asked what could be done to one sheet of paper to ensure that it would hit the ground in a shorter period of time than the other sheet. Through discussion and demonstration the students found that a scrunched piece of paper falling down would hit the ground earlier than a flat sheet of paper. This led to a group challenge whereby the students would investigate other ways in which one sheet of paper might be changed so that it would hit the ground sooner than the other.

Once the task was given the open carpeted space was then used by the students to undertake the task. Apart from the open spaces students were also able to use the large table areas if they wished. Chairs were often stacked in the corner so students might also use the spaces between the tables. The openness of the classroom gave sufficient space for students either singly or in small groups to comfortably undertake their inquiry-based tasks. There was also sufficient space for Mr Roberts to move freely among the students asking questions of them as to their findings.

The students were also able to move around to observe other students or to eagerly announce to Mr Roberts their findings on the given task.

The nature of the tasks given to the students sometimes warranted using a larger space than was provided for inside the classroom. For example, in the open space outside the classroom students explored the performance of a lever used as a catapult when the position of the fulcrum was changed.

Apart from students developing key ideas associated with forces, Mr Roberts also wanted the students to develop their inquiry skills. He would give them equipment for a particular problem and expect the students to apply a methodological approach of their construction in solving the problem. For Mr Roberts the tasks were given with "fair testing as a base… it's a good opportunity to introduce, to reinforce, the fair testing while also doing forces." One such task involved students investigating the phenomenon of friction. In groups they were provided with balls of various sizes, a large plank, a long strip of sandpaper and a long strip of carpet, and a stopwatch. The students were to compare the effects of friction on a ball rolling down an incline with different surfaces such as wood, sandpaper and carpet. The nature of the task required the students in each group to work collaboratively in the design of the methodology, data collection and the construction of evidence to support claims about findings that were reached. The class discussion on the carpet space that followed this task centred on ideas about friction as well as methodological issues encountered by the students in collecting data.

On another occasion the EQUALPRIME team witnessed a lesson in which the students had to do research about chemical and physical changes. Mr Roberts had sent them an email with the homework. Now they checked what happens when sugar is burnt over a flame. They had to weigh the material before and after the burning in small groups and while some students burnt the sugar, others wrote a description of the situation on a tablet computer and still others documented it all, taking pictures with the tablet computers and sending them to the teacher. Thus after the lesson the teacher received a written description and a series of pictures from every group's work on his computer, enabling him to assess what the groups had done and found out.

If we consult our analytical questions which we developed above on the basis of historical room designs, Mr Roberts' classroom may be categorised as follows:

In all, Mr Roberts purposefully used the physical classroom space and equipment to support an inquiry-based teaching and learning environment. In line with the Reggio philosophy he purposefully designed the classroom learning space to provoke and encourage exploration and problem solving. Above all, however, this classroom can be regarded as a modern version of a classic Freinet workshop:

- The spatial arrangement of the teaching offers opportunities for the children's free activity on questions the children have set themselves or which the teacher has brought into the class (analytical question 4).
- There are numerous activity options for productive work by the children, including tools, a wet zone and publication tools (question 5).

- The materials are clearly up to date, while the charming, rather old-fashioned illustrative objects combine beautifully with the most modern digital teaching tools (question 2).
- The children have the resources which allow them to work properly in their investigations, just as grown-up artisans, artists or scientists would do (question 6).

Although artistic activities or historical observations of nature and the natural sciences (question 9) would not be out of the question in this room, in view of the fact that each class only spends 60 min a week in this room there is very little time available. In addition, aesthetically the room is no doubt not as consistently styled as a Montessori classroom. Nonetheless, one may clearly speak of a well thought-through ‘prepared environment’, albeit distinct from a Montessori classroom (question 1). Mr Robert’s classroom is very much geared to the natural sciences and scientific forms of work, without there being any laboratory atmosphere about it. It is evident that a science didactics is being conducted which is not primarily reliant upon or directed towards technical implements and measuring instruments but which fosters the pursuit of simple phenomena with simple technologies as well as a scientific attitude in dialogue about the subject.

The room also shows how Montessori’s idea of the ‘prepared environment’ may be understood in relation to science in the twenty-first-century classroom: a subject room which is not quite a laboratory but is already geared towards scientific work and scientific reasoning and which, most importantly, provides an explicit surface on which scientific reasoning can also occur.

Case Study 2: Ms Lennard’s Room (Germany)

Ms Lennard teaches at a private Protestant confessional school in a prosperous suburb of Berlin. The school was established in 2004 and is situated on a green site close to woodland. Approximately 300 children from Grades 1–6 attend this school, which places three grades together in each learning group: Grades 1, 2 and 3 and Grades 4, 5 and 6 form multi-grade classes. School attendance is not free; parents pay (in 2015) between 27 and 568 Euros per month, depending on their income.

The school has a music room at its disposal, a medium-size library, a science room and a generous, very green outside area. It is a full-day school, compared to many other schools in Germany which are mainly half-day schools, in which many creative activities take place, projects, sports events, nature explorations, theatre, and musical productions as well as class-trips for the whole school are regular features of the school’s life. The school has a strong focus on ecological education.

The class we visited had 25 students: 12 boys and 13 girls. There were seven children with special needs in this class and the school had inclusion as an aim. We could not identify the disabled children at first glance, which means that they were perfectly integrated in the group of students.

Being quite independent from the state, this school develops its own curriculum in weekly team meetings. We observed lessons on forces and the principle of the lever. There was a second teacher in the class for some units, Mr Arnold, and the teachers were team-teaching for this unit. Congruent with the holistic philosophy of the school, both teachers do not regard force as being a physical term only; in their eyes, force can be found in arts and crafts and language as well and the school should open the eyes of the students to this richness in meaning.

Both Ms Lennard and Mr Arnold are generalist teachers, although they have studied *Sachunterricht* (a comprehensive subject in German primary schools which includes both natural and social science; see Chap. 2). They follow the Dialogic Learning approach developed by the Swiss pedagogues Ruf and Gallin (Gallin 2010; Ruf and Gallin 2005). Both are very interested in science and they took part in an innovative school development project for primary science called *prima*(*r*)*forscher* ('primary scientists') which lasted several years. They are focused on scientific explorations and understanding of phenomena.

As Ms Lennard pointed out:

> One will definitely notice in this unit that the children come with different preconceptions. However these differences are not only caused at school but also come about through everyday life. And we try and make this a basic principle. So dialogical learning is a main point for us, and this is also true for natural science, this means science for us has less to do with formulas and studying principles, but rather with a process of understanding. There is a common subject matter, the phenomenon, which needs to be explored. There are different points of view in the discussion of this: How do I see it, how do you see it? How come you see it the way you do? So it's a sort of comparison. (From pre-Unit Interview.)

The school building was designed to suit the school's pedagogical philosophy. Classrooms are grouped into units of two with separate entrances from the corridor. Each unit also includes an anteroom for group activities and a teachers' room between the classrooms which can be accessed from both classrooms. The school has a science laboratory with fixed tables. But the teachers decided not to use the room for the lever lesson. They explained that they need flexibility and, similar to Mr Roberts in Australia, room on the floor for discussions and activities.

In comparison with Mr Roberts' classroom in Australia Ms Lennard's classroom was rather sparingly equipped (Fig. 3.6). In this quite pleasantly and colourfully decorated classroom there were essentially five groups of tables for four to six children each and a teacher's desk next to the blackboard. The classroom was equipped with a traditional blackboard, a few shelves with drawers for each child, a book shelf containing some books and educative games and a sink. At the beginning of each lesson the teacher reminded the students to leave nothing but their large pencil cases on their desks and to place all other personal belongings into their large colourful satchels which they kept on the floor beside their desks. Some more books and computers were available in the group room. However this room was not used during the lessons observed in this unit.

The first thing that struck the visitor was that there were hardly any books or science equipment of any kind in the room. The lesson started with an odd-looking phenomenon on a photo which the two teachers had projected onto the wall.

Fig. 3.6 Ms Lennard's classroom: A room concentrating on scientific discourse

(For a more detailed account of the lesson see Chaps. 6 and 8). Consistent with the pedagogy of Gallin and Ruf the children were asked to let their imaginations run free and to write all that came to their mind in their research journals. Following this the children exchanged places. Their journals stayed where they were and each child read and commented on another child's text.

This was repeated a number of times, so that all the children received feedback on their thoughts from several fellow students. The teachers collected the texts and analysed them after the lesson, selecting a few sentences to be presented to the whole class as so-called 'autographs' in the next lesson. Then they all worked together on an 'autograph', a sample from one or several students. As one of the two teachers put it: "We look for sentences that we can all think about further." This is the way the teachers focussed on the topic. This produced several hours' worth of dialogue on the children's own ideas on the phenomenon to be analysed. The subject in this case was the forces on a lever arm and how, when using a long lever arm, one can balance heavy weights with a lighter counterweight.

The lesson was conducted mainly verbally and moved along with lengthy, calm discussions of the subject on the part of the students. The teachers did not offer much information, simply allowing the children to present their interesting ideas and reflecting them back into the class over and over again. When some practical experience was called for, the teachers handed the children small wooden rods and a handful of building blocks and asked them to reproduce the situation in a small desk experiment (Fig. 3.7). This helped the children to see for themselves the relationships between lever arm and load arm, weight and counterweight. The children were asked to draw their design and write down their observations into their research journals. Later on they were asked to experiment with different weights and produce a table of their results. In this way they also developed a first form of mathematisation

Fig. 3.7 Testing the law of the lever with simple building bricks at the edge of the table

of the principle of the lever in the shape of a table expressing the relationships between the entities concerned in measurements.

Step by step the children discovered the law of the lever through their dialogues with fellow students. The children tested their findings, finally, in the schoolyard with large, heavy levers (see the dialogues and photos in Chap. 8 on embodied strategies). The teachers followed a clear logical sequence, similar to the 5Es model (Hackling et al. 2007) popular in Australia:

Step 1: Bring the phenomenon into focus, take up the children's conceptions and ideas
Step 2: Focus preconceptions
Step 3: Test and document
Step 4: Reflect.

Whereas in other science classes in Germany experimentation is frequently the main focus of all activities, and hands-on activities are regarded as especially important, here in this class scientific reasoning itself was clearly the main activity. Almost all the knowledge gained was produced through the children's dialogues, for which the teachers allowed an unusual amount of time. These lengthy dialogues were a real surprise to the research teams from Australia and Taiwan.

In terms of room design, the contrast with the previously described example from Australia could hardly be greater: while Mr Roberts' class overflowed with materials of all kinds, Ms Lennard's classroom was furnished very modestly. Only the most essential objects were handed out to the children. Besides these, they had virtually nothing more than their imagination to work with to produce ideas and solutions. The room itself was no more than the departure point, which constantly changed as the teachers brought in new materials each day. These materials then provided inspiration for further thought. There was no need for computers or books. It is true, however, that the children came primarily from academic families, where presumably they had many books and other illustrative material to hand. They also had above average language skills. It may be assumed, also, that many of them regularly watch one (or several) of the many dozens of popular science television programmes that are broadcast weekly into homes on the various TV channels in Germany. They were entirely familiar with thinking and arguing in the context of cause-effect and end-means relationships.

The outdoor area was also used for experiments. Here the teachers had prepared large, heavy wooden beams on which the students were to lift their fellow students into the air using the law of the lever "using one hand only!" (See the picture in Chap. 8).

Applying the analytical questions discussed in our introduction, taken from progressive education concepts of the last century, the difference to a typical Montessori class is obvious: There were only very few materials in the room and definitely no material at all that could be used for one purpose only as it is typical for the Montessori material (analytical question 1). On the other hand, applying our second analytical question, it may be noted that the students did have the freedom, with the aid of a phenomenon provided by the teachers, to make the world their own for extensive phases of the time allocated to this subject. The phenomenon chosen by the teachers was challenging as it did not impose one single way of interpreting the situation. It challenged the children to give meaning to the situation themselves. The two teachers did, however, guide the overall course of the lesson very clearly by giving special emphasis to some of the children's statements while not following up on others.

Thinking of Freinet's concept of the classroom as a workshop, there was not too much at hand for the children in Ms Lennard's class but only a restricted variety of carefully selected materials to stimulate the children and with which they could help themselves in bringing their questions to an answer (analytical question 4). The children had to rely more or less on their own powers of argumentation. But fully compliant with Freinet's dictum of the "expression libre" the students were absolutely free to articulate every idea and thought about the phenomenon in question, being sure that every utterance would be acknowledged by their teachers and fellow students. And they definitely worked as seriously as grown-up scientists would do (question 6).

The students did not receive many stimuli in the form of objects for learning in the classroom to help them understand the context of nature, culture and social life (question 8), but had to produce all insight into the phenomenon by themselves. However the teachers encouraged the students to draw analogies to their daily life and consider not only scientific but also cultural and social aspects of the phenomenon in question. Most importantly the children received rich comments from their fellow-students on their individual thoughts and ideas, enabling them to find a law of nature by independent thinking in the shared dialogue in the class.

Although, with the exception of a sink, there were no real work zones in the room, there were sufficient possibilities in the classroom for productive work (question 5). However, the children mainly used paper and pencil and their research journals to detect the law of the lever. If they needed objects to test their thoughts and ideas, the children could move around the classroom freely and use the materials which had been provided by the teachers. In turn, the children then made very intensive use of the little material they had, as they themselves decided, and used the materials to test their hypotheses themselves. So the productive work was mainly intellectual activity supported by a very limited supply of materials. Using the image from the Reggio pedagogy of the 'room as the third educator' in this arrangement the 'first educators' – that is to say the fellow students – and their utterances were much more important than the second and third educators, that is the teachers and the room. In this case, the room as the 'third educator' worked not by its richness and abundance in stimuli as we could see in Italian crèches and kindergartens but by its very sparseness, as it forced the children to rely on their own resources and the power of their dialogues, which the children carried out with utmost respect for each other's thoughts.

Case Study 3: Ms Hong's Classrooms (Taiwan)

The last classroom environment considered here is situated in an inner-city school of more than 1,500 students in Taipei. We begin with a description of the building, the science classroom and a special so-called 'e.future classroom', before moving on to an analysis of these two rooms.

Description

The school is in some parts six storeys high and is arranged in terraces, backing onto a hill slope. The four wings of the school building enclose a large, leafy inner courtyard with tall palms and coffee plants arranged in terraces, giving the whole school a green hue.

An introductory video mentioned the school motto, "A place of happiness – a place of discovery". The principal explained that the parents are pleased if the children enjoy going to school and are happy here. It is the school's duty to produce such times of happiness. The school administration is supported by a very active parents' committee. On the day of our visit a large display of books for sale had been set up in the school hall, and all the parents were encouraged to buy books for their children, as a boost to their enjoyment of reading.

The rather small and somewhat chilly classrooms with light tiled floors and traditional school tables were on the whole sparsely furnished. The children sat on small wooden chairs at traditional two-person desks, facing the board. All the classes were, however, fully equipped with electronic devices: there were data projectors and television sets in nearly every room. In the lessons the teachers made frequent use of microphones and loudspeakers to project their voices.

This school applies the subject-teacher principle as early as the third grade; that is, the teachers of science lessons are specialists in this field. For their ongoing

Fig. 3.8 Miss Hong's science room

personal development the teachers participate in conferences in their subject and attend weekly meetings.

The school has several science classrooms, each of which is assigned to two or three teachers who carry out their science lessons mainly in their designated science classroom and are also in charge of preparing the environment with materials, resources and representations. Ms Hong's science classroom has six rectangular tables which are placed in two rows with the short side of the tables facing the blackboard. Three children sit on metal stools on each side of a table, facing each other and with their back to the row of tables behind them (see Fig. 3.8). In order to look at the blackboard they have to turn at right angles. The teacher mostly stands in front of the blackboard, which is a traditional blackboard for chalk with an integrated interactive whiteboard. The walls to the left and right of the blackboard are decorated with astronomy posters. There is an elevated long teachers' desk in front of the blackboard with a metal surface and a sink on the side. To the right of the blackboard there is a laboratory cart and to the left there is a smaller table with a computer and a printer. A monitor is hanging from the ceiling and speakers can be seen above the blackboard. Like many Taiwanese teachers, Ms Hong sometimes uses a microphone to rest her voice when talking to the students. The students themselves also use a microphone which is passed around during whole class discussions.

The students attended three 40-min science lessons a week. The school has an emphasis on teaching astronomy at an early stage. It has its own remotely operated planetarium and a collection of numerous astrolabes, large light tables with colour photographs of parts of the universe, star charts and telescopes. In a corner of another room used for astronomy classes we saw large, brightly coloured polystyrene balls of various sizes, skewered onto wooden rods, with which the students can imitate the movements of the planets in role-play. Children are introduced to the use of the telescope in their early years, and several times each year the school takes the children on evening trips into the countryside, where they can view and admire the stars against the dark night sky, unpolluted by the glare of the city.

While most of her science lessons take place in this science room, Ms Hong also uses the outdoor campus ground, for example, to practice the use of the astronomical quadrant to measure the inclination of a celestial object.

A special room in this school is the so-called ‘e.future classroom’ designed by the school “to explore new ways of integrating technology into the learning environment to create a richer learning experience for students and teachers alike” (School Concept Paper). The paper further states: “The hardware facilities of the e.future classroom include specialised desks, nine student desktop computers equipped with touchscreens, four main control computers, large multi-touch screens, touch screens with rear projection capabilities, a blue-screen digital video booth with a digital video camera, multimedia editing studio and multimedia recording facilities.” The authors explain,

> Interactive projection technology is the foundation on which we have built a flexible learning platform for students to learn and experience different environments …. Students can learn together through the video conferencing platform and distance-learning facilities, with no limits on their location or which class they are in …. By combining our school’s astronomy curriculum and opening the observatory to remote learning, students are able to see beyond the planet we live on and learn about the mysteries of outer space….The e. future classroom has been designed to complement both current and future curricula, and to offer teachers greater flexibility in presenting their lessons, while encouraging students to explore topics in greater detail, while enabling them to work with students in other classrooms, cities or even countries (Li and Hale 2015).

The room is window-less and made of grey fair-faced concrete with large black decorative features and black rubber-studded flooring. The whiteboards can be linked together to make even larger screens. The pictures on the interactive whiteboard (IWB) can be hyperlinked with multiple external sources, video scenes, still pictures and also written utterances by the students on their electronic tables.

The students’ tables consisted of a flat, horizontal interactive computer monitor, attached to which were four small black fold-away students’ desks, in a wing-like configuration. Four children shared each of these wing constructions, perching on colourful foam-rubber cubes without back supports. The children wrote with electronic pens with built-in cameras. Their written work was transmitted to the school computer and could be shown immediately on an IWB and, while the child was still writing, could be corrected or commented on by the teacher in front of the other students. All the children’s written products were saved for assessment by the teaching team later.

In one corner, beside an especially large IWB there was a lectern, of the kind one sees in conference rooms, supporting a large flat screen. And behind a large glass screen there was an assistant ready to provide the media: pictures, films, copies of the students’ work from past sessions; and, many other things, projecting them on the various IWBs at the teacher’s request. The room was equipped with cameras,

Fig. 3.9 The e.future room

and all the lessons could also be filmed for the purposes of school research and teaching assessment (Fig. 3.9).

There were 28 students in this fourth Grade class. The unit was about positions and movements of the Moon and the objective of the unit was "to perceive the phenomenon of the Moon rising from the East and falling in the West" (pre-unit teacher interview). The unit started at the beginning of the semester in the month when the 'Moon festival' takes place (August 15 in the lunar calendar). Each science unit usually takes one month and in the whole semester the students will learn four different units.

Our visit to the school took place in December when the astronomy unit had already been completed, and the teacher used the opportunity for an assessment of the students' long-time knowledge in the e.future room. The lesson began with a repetition of the Chinese lunar calendar, in which there is a full Moon on the 15th of each month. At the same time, on the IWBs there were projections of calendar pages with the daily changing views of the Moon, a representation of the various phases of the Moon dependent on the relative position of the Moon to the Sun and the Earth, as well as pages of text from the schoolbook, also provided by the publisher of the schoolbook as digital images. The teaching material was linked to the textbook, which closely follows the Taiwanese national curriculum and at their group tables the students were asked to observe and analyse the various stages of the Moon in November and December on a work page. The same work page was also presented on one of the IWBs. The results of the group work were then transmitted via cameras directly onto an IWB, so that the whole class could see and compare the various group findings.

The Chinese and Gregorian calendars were shown side-by-side on two IWBs, so that the children could quickly see the differences. This is an important topic in Taiwan because here both calendars are in use at the same time: the Gregorian calendar for trade, commerce and business, and the traditional Chinese lunisolar calendar for determining the annual festivals and traditions.

After this, the Chinese festivals were identified in the lunar calendar and discussed. Later illustrations from fairy-tale books were projected onto the IWB and traditional Taiwanese moon poems were recited, creating a seamless transition from the scientific analysis of the movements of the Moon to a discussion of the children's cultural heritage. This connection between the scientific worldview and the cultural interpretations of the world is explicitly mentioned in the Taiwanese national curriculum.

Analysis

The members of the Australian and German EQUALPRIME team were extremely impressed by their visit to this school and especially the e.future-room. They had not seen a highly equipped electronic classroom of this kind in their own countries. Some of them initially felt uneasy: a completely window-less room for little children? This did not seem at all 'child-friendly' at first glance. The grey concrete and the large amount of black with the many simultaneously illuminated IWBs, which the teacher operated expertly with a microphone in her hand, rather conjured up spontaneous associations with command posts of air traffic controllers or technicians in high-tech industrial plants. In fact some of the guests found it inconceivable that such a room could be 'a place of happiness' for children of primary school age.

The primary school children, however, immediately corrected this impression. They entered the room completely relaxed, chattering just as happily as children everywhere else in the world. As most children of today in highly developed countries they were used to large flat screens from their homes and the commercial environment; such high-end technology products had been part of their everyday lives since birth. And Taiwan is one of the most important producers of digital technologies for the whole world. Why should a school in Taiwan use different media from those that form the very basis of the country's economy?

The students did in fact follow the lesson with great motivation and a high level of participation. The use of the different media and graphic representations, the combination of teacher's questions, illustrative materials and utterances of the students produced an extremely meaningful sequence of learning steps which the students picked up in very short order. Much of the course of the lesson was guided by a series of questions on the part of the teacher. The students' engagement was largely in receptive or reactive mode, but they were able in the group phase to exchange ideas quietly with each other. The level of intellectual challenge was exceptionally high and, to the observers from Europe and Australia, the changes of lesson phase took place at an astonishing speed (see also Chap. 2). The direct comparison of the Gregorian calendar with the traditional Chinese calendar side-by-side on two IWBs made it easy to spot the differences between the two calendrical systems. The teacher made a highly professional impression on the visitors.

If we apply our analytical questions from the Progressive Education of the twentieth century to this room design and room use, then Maria Montessori's term 'prepared environment' gains a whole new meaning. Let us recall the first three analytical questions:

1. Does the classroom represent a prepared environment in such a way that the furniture and the materials available to the children are placed purposefully and can readily be used for predetermined purposes?
2. Do the materials and the physical environment provide a stimulus for ordering things which the child can take on board and internalise?
3. Do the students have the freedom, with the aid of the materials provided, to make the world their own for extensive phases of their development?

It is quite clear that the first two questions can be answered unequivocally in the affirmative. Yes, this was a prepared environment in Montessori's sense, even if shaped by the media of the twenty-first century representing a prepared environment for children of the digital age. And yes, the media offered here did lead the children closely toward predetermined learning in just the way the Montessori materials did in the first half of the twentieth century. And yes, the students did have the freedom, with the aid of the materials provided, to make the world their own for extensive phases of their development, but the perception of the world obviously was completely pre-determined by the schoolbook, the media and the course of the lesson unit. The subject of the lesson may be narrowly focussed on a clearly defined phenomenon, but it was underpinned very broadly with practical observations and examples of application and very intensive dialogues on the variously presented representations (see also Chap. 7).

And one of the demands of Reggio pedagogics was given a new, contemporary interpretation in this learning arrangement: the students not only had opportunity for rational analysis of the environment with the traditional tools of science and mathematics (analytical question 9), but also gained an insight into the cultural and historical background of their local situation in which they live and in which the scientific knowledge gained becomes effective in practice. In the digital classroom the scientific interpretation of the world was linked to the legends and traditions of history which are still effective in the children's families and which the students' science teacher brought to them with the same seriousness and engagement as the differences in time calculation in the two calendar systems discussed.

Conclusions

On our field trip to three continents we saw three classrooms, which could hardly have been more different from each other:

- in Australia, a traditional workshop with ample opportunities for hands-on activities, one indebted to the praxis of inquiry-based learning widespread in that country;
- in Germany, a rather sparsely furnished classroom for learning in and through dialogue with a few well-chosen materials acting as stimuli for the children's inquiries; and,
- in Taiwan, a high-tech classroom, representing the contemporary technology-enhanced instructional setting, which is a school-based innovative effort in pursuit of the so called 'future development oriented' teaching practices.

The communicative approach differed considerably between the three cases. In the first two case studies the teachers responded very much to the thoughts and ideas of the children, who were thus able to influence the course of much of the lesson. The main contribution of the teachers consisted in constantly keeping the children to the topic and providing them with a room that could be used in different ways, and with a wide variety of materials with which the children could immediately try out their ideas themselves in practice.

In contrast, in Taipei the course of the lesson in the digital classroom was largely guided by the graphic representations that the teacher brought into play. Ms Hong could use the room in a wide variety of ways. This room did not provide opportunities for hands-on activities. The class spent 5 of altogether 15 lessons on the Moon in the e.future-room. Here, all the learning occurred in the students' heads; in their interaction with texts, pictures and animations. Hands-on activities such as experimentation with objects and models took place in the normal science room which the teacher used for most of the lessons. Astronomy proper takes place, of course, at night when the children make observations of the Moon at home with their parents, then bringing their notes to school and following the movements of the constellations in the digital classroom. Or on night-time walks in the country, where the children can experience the beauty of the starry sky and so learn to connect science with the mythical conceptions of humanity.

Observation of the differences between the classrooms analysed also shows common features between the teachers: all the three teachers demonstrated an extraordinary interest in, and considerable knowledge of, the natural sciences. This allowed them also to make high intellectual demands of the children and to use the rooms they had prepared for the purpose with great expertise. In all three cases sustained conversation of high intellectual quality was the core method of teaching. As Lemke writes, science ideas have to be talked into existence. So learning science involves talking science (Lemke 1990). The classroom, however it might be designed, in the first place is only a wrapping for this kind of talking.

But this wrapping is by no means arbitrary. When one compares the three learning environments it becomes obvious that there is no single ideal learning environment for science teaching. Different spatial designs can support science teaching of high quality. The teaching quality is thus not directly dependent on the quality of the environment. Rather it seems that quality depends on a certain harmony between the teacher's personality, his teaching conceptions, style and methods and a fitting environment, all of which have cultural and historical roots. Thus it appears that the answer to the question of what a perfect primary science teaching room should look like; is that there is no such standard science teaching room. The ideal room is always an individual creation. It follows that teachers should ideally be granted great freedoms in designing their personal science learning environments to fit their educational philosophies.

To conclude our field study, we would like to review our research method: we started our fieldtrip through three classrooms on the assumption that we could use analytical questions derived from three pedagogical concepts, which were all closely related to the progressive education movement of the early to mid-twentieth century. These ideas, of course, can no longer be considered the norm for the design of science classrooms in the twenty-first century, especially not for any cultural setting. But they still hold a potential which may be used for a critical look at current conceptions of space and education. These historical pedagogical concepts have served as eye-openers even though our views on high quality science teaching may differ considerably from the pedagogies of the twentieth century progressive education. But at least some of these historic principles still provide ideas on what to look for when thinking about up-to-date science environments for quality primary education.

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Chapter 4
Variation in Whole Class, Small Group and Individual Student Work Within and Across Cultures

Mark W. Hackling, George Aranda, and Ines Freitag-Amtmann

Background

Each instructional setting has particular affordances for the effective implementation of various teaching and learning strategies. Whole-class instruction is often used to review past work, check students' prior knowledge or to introduce new work to the entire class. Working with the whole class builds common experiences and provides a shared basis for investigations and problem solving. Small-group instruction is often used for materials-centred, hands-on activities and for group discussion tasks. Some teachers also use small groups as a basis for differentiating instruction for different ability groups. Individual activity is commonly used for assessment tasks and to provide opportunities for students to clarify their own thinking about ideas discussed collectively and to record journal entries as summaries of what has been learned.

There are complex relationships between instructional settings, teaching and learning strategies, nature of academic tasks and opportunity to learn. Each setting has affordances and constraints that influence which teaching and learning strategies can be effectively implemented. For example, student to student discussion is best implemented within a small-group setting within a cooperative learning ethos where students are sitting in a face-to-face configuration. Each academic task has unique cognitive demands (Doyle 1983) and the successful accomplishment of the

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tasks requires students to be intellectually engaged in particular ways which are facilitated by the teaching-learning strategy adopted. Thus the alignment of instructional setting, strategy and task determine students' opportunity to learn (McDonnell 1995).

Teachers draw on their pedagogical content knowledge through pedagogical reasoning to make choices about settings, strategies and tasks (Shulman 1987); however, they are also influenced by their own personal philosophy of education and beliefs about the nature of science and effective teaching (Gess-Newsome 2015). Teachers who have strong personal commitments to child-centred learning, social constructivist philosophies or to inquiry-based science education will want to give children opportunities to work on investigations, make observations and construct explanations for themselves. Such teachers are likely to maximise opportunities for small-group, collaborative and materials-centred activities.

Hashweh (1996) argues that "constructivist teachers view the development of knowledge at the individual level and in science as a process of conceptual change" and that these teachers use strategies that reveal students' alternative conceptions, confront them and facilitate cognitive restructuring as these strategies "are more in harmony with the teachers' constructivist beliefs than other less effective strategies, such as the presentation of information and repetition-strategies that are incongruent with constructivist beliefs" (pp. 61–2). This research demonstrates the strong influence of teachers' epistemological beliefs on their choice of instructional strategies. The effectiveness of strategy implementation will be enhanced by an appropriate matching of strategy and instructional setting. Research by Benson (1989) has demonstrated that teachers' beliefs have a stronger influence on teachers' instructional choices than contextual factors; however, more recent research (e.g., Stigler and Hiebert 1998) indicates that social and cultural factors provide a strong framing for the ways in which teachers implement the science and mathematics curriculum.

Stigler and Hiebert (1998) argue that teaching is a cultural activity and teaching and learning behaviours are governed by culturally determined scripts:

> Cultural activities are represented in cultural scripts, generalized knowledge about the event that resides in the heads of participants. These scripts not only guide behaviour, they also tell participants what to expect … [and] … one of the reasons that classrooms run as smoothly as they do is because students and teachers have the same script in their heads; they know what to expect and what roles to play. (pp. 1, 2)

The TIMSS science video study (Lokan et al. 2006) and cross-cultural video studies in mathematics education (e.g., Clarke et al. 2006) have demonstrated that there are distinct culturally framed ways in which teaching and learning are transacted in different countries. It is to be expected, therefore, that teachers of primary science will make choices about instructional settings that are consistent with their beliefs and the social and cultural contexts in which they teach.

This Chapter investigated the extent and frequency with which teachers used the instructional settings of whole-class, small-group and individual student activity, and explored teachers' views about how these choices are influenced by their beliefs and contexts.

Methods

All of the Australian, German and Taiwanese data for the EQUALPRIME study were collected following the shared repertoire negotiated between the research teams (see Chap. 1 for further details). This Chapter draws on two data sets; the video recordings of lessons made by the camera that followed the teacher; and, teacher interview data. The video data were analysed to determine the teachers' use of instructional time whilst the interviews were used to probe the teachers' perceptions about reasons for variation in use of time.

Analysis of Video Data

Case studies were collected in Melbourne, Perth, Berlin and Taipei by the four research teams. This involved a total of 14 cases and 16 teachers; one Australian case and one German case involved two teachers team-teaching for science lessons. A total of 142 lessons were video recorded (Table 4.1).

The coding of teachers' use of instructional time was completed by researchers from each country. This ensured that the lessons were analysed by researchers who spoke the language that the lessons were conducted in. Each lesson was analysed according to changes in activity throughout the lesson so that the amount of time for each lesson episode could be coded into non-instructional time (NIT), whole-class activity (WCA), small-group activity (SGA) and individual student activity (ISA), and changes between activity categories could be observed. The total time for each activity category was calculated for each lesson and then aggregated across all lessons for each case study. The total time was then converted to percentage values for each case. It was stipulated that only events that continued longer than 30 s were coded as an activity.

To ensure a consistent approach to coding the use of instructional time, definitions of the four categories guided the coding process.

Table 4.1 Numbers of cases, teachers and lessons captured for case studies by the research teams

Country	Location	Cases	Teachers	Total lessons	Lesson range
Australia	Melbourne	4	4	40	6–17
Australia	Perth	3	4	26	8–9
Germany	Berlin	2	3	13	6–7
Taiwan	Taipei	4	4	63	11–21

Definitions of WCA, SGA, ISA and NIT

The definitions of Whole Class Activity (WCA), Small Group Activity (SGA), Individual Student Activity (ISA) and Non Instructional Time (NIT) are provided below with relevant examples.

Whole-class activity (WCA) was defined as those parts of the lesson where the whole class, or nearly all members of the class worked together on a particular activity that the teacher was co-ordinating; for example, whole class discussion, teacher demonstration to the whole class, expository teaching.

Small Group Activity (SGA) was defined as those parts of the lesson where members of the class were divided to work together on tasks in groups greater than one student; for example, small group discussion, working on experiments.

Individual Student Activity (ISA) was defined as those parts of the lesson where members of the class worked on tasks individually; for example, students writing in their journals, individually examining artifacts.

Non Instructional Time (NIT) was a category for moments that did not fit into the categories listed above. These were times when no instruction was occurring. For example, moments in the lesson when the teacher was organising the students or addressing administrative matters. These episodes of NIT typically occurred at the beginning or ends of lessons.

Those times in the lesson when the attention of the students was drawn back to the teacher, where the teacher addressed them as a whole group were coded as WCA. For example, when students were working in small groups and the teacher stopped the work they were doing and addressed them as a group to highlight the good work of a particular student or to clarify a procedural issue.

Analysis of Interview Data

The digital audio recordings of teacher interviews were transcribed verbatim. Transcripts were repeatedly read until themes began to emerge in a bottom-up way typical of a grounded theory approach to analysis (Corbin and Strauss 2007). As the teachers' beliefs regarding effective science teaching and choices about instructional settings became clarified, individual teacher statements that exemplified their views were identified and used as quotations to illustrate the narrative developed in reporting the data.

Results

The analysis of video data revealed how instructional time was used for the different instructional settings and teacher interviews explored the factors that influenced the teachers' use of time. The quantitative data regarding use of time is reported first, followed by the qualitative data regarding the factors influencing choices made by teachers about their use of the classroom settings.

Teachers' Use of Instructional Time

The use of instructional time within the set of lessons for each case was collated into the categories of non-instructional time (NIT), individual student activity (ISA), small group activity (SGA) and whole-class activity (WCA). These data are summarised in Table 4.2 for the Australian, German and Taiwanese cases.

The available time was used efficiently in most cases in that little time was used for purposes other than instruction. In only two cases did non-instructional time exceed 3 % of the available time. The mean per cent NIT was higher in the Australian cases than in the German and Taiwanese cases; however, the differences between countries were small. Instances of NIT in the Taiwanese cases were less than 30 s and were therefore not coded.

Table 4.2 Percentage instructional time utilised in different instructional settings for Australian, German and Taiwanese case studies

Australia (A)	**Case**	**NIT**	**ISA**	**SGA**	**WCA**
	1	3.5	0.0	19.6	76.9
	2	0.3	16.0	30.6	53.1
	3	3.0	11.0	39.0	47.0
	4	4.8	9.4	47.5	38.3
	5	0.0	15.6	29.7	54.7
	6	0.8	10.2	17.3	71.7
	7	0.0	12.1	37.2	50.7
	Mean (SD)	**1.8 (2.0)**	**10.6 (5.3)**	**31.6 (10.7)**	**56.0 (13.6)**
Germany (G)	Case	NIT	ISA	SGA	WCA
	1	0.0	22.9	18.0	59.1
	2	1.4	10.3	27.8	60.5
	Mean (SD)	**0.7 (1.0)**	**16.6 (8.9)**	**22.9 (6.9)**	**59.8 (1.0)**
Taiwan (T)	Case	NIT	ISA	SGA	WCA
	1	0	4.3	6.6	89.2
	2	0	3.1	0.0	96.9
	3	0	20.7	31.8	47.5
	4	0	18.3	16.5	65.2
	Mean (SD)	**0.0 (0.0)**	**11.6 (9.2)**	**13.7 (13.8)**	**74.7 (22.6)**

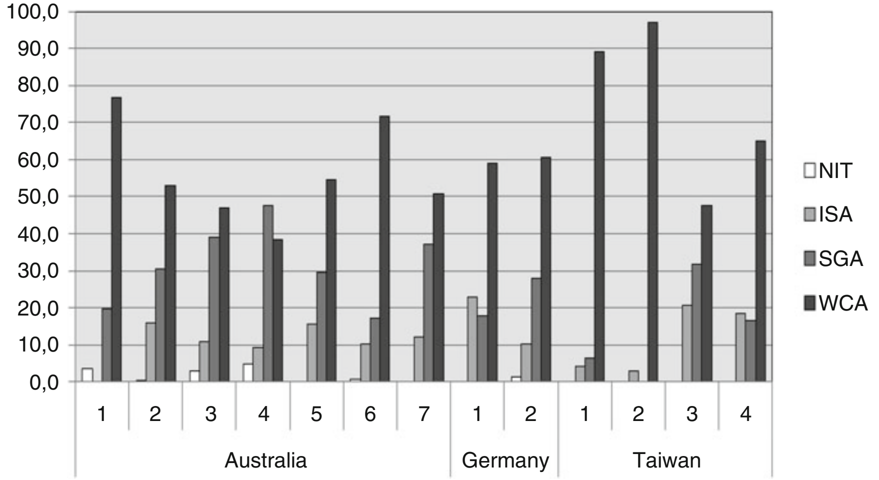

Fig. 4.1 Percentage instructional time utilised in different instructional settings for Australian, German and Taiwanese case studies

The proportion of time used for whole-class activity varied considerably between cases from as little as 38.3 % in an Australian case to a high of 96.9 % in a Taiwanese case. Only two of the seven Australian case study teachers used more than 60 % of class time for whole-class activity whilst only one of the four Taiwanese case study teachers used less than 60 % WCA.

The proportion of time used for small-group activity varies both between countries and teachers within each country. Mean SGA was highest for the Australian cases (31.6 %), less in the German cases (22.9 %) and lowest in the Taiwanese cases (13.7 %). The difference between the percent SGA used in Australia and Taiwan is likely to reflect the cultural setting in which science teaching occurs. However, use of SGA also appears to be a distinctive feature of some teachers' practice as within each country some teachers use far more SGA than their compatriots. For example, within the Taiwanese cases, the use of SGA varied from zero per cent to 31.8 %.

Although the mean percentage ISA is higher for the German cases than for the Australian and Taiwanese cases, there are teachers in each country that use little time (<5 %) for ISA whilst others use more than 15 % ISA. The variations between case study teachers' use of instructional time can be seen clearly in Fig. 4.1.

Figure 4.1 clearly demonstrates the overall pattern in the use of instructional time; i.e., most time is devoted to WCA and progressively less time for SGA, ISA and least of all is NIT.

Data from teacher interviews were used to elucidate the impacts of their beliefs about effective teaching and their cultural and social settings on their use of instructional time. It was anticipated that differences between country means would be influenced by cultural and social factors, whilst variations between teachers within a country could be explained by the teacher's own philosophical values and personal beliefs about effective teaching.

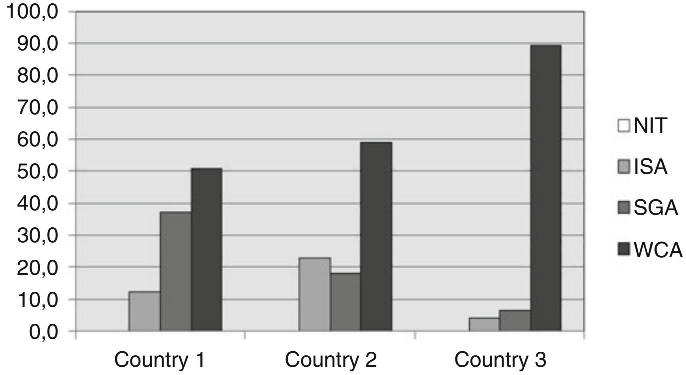

Fig. 4.2 Use of instructional time (percentage) in one case study from each country

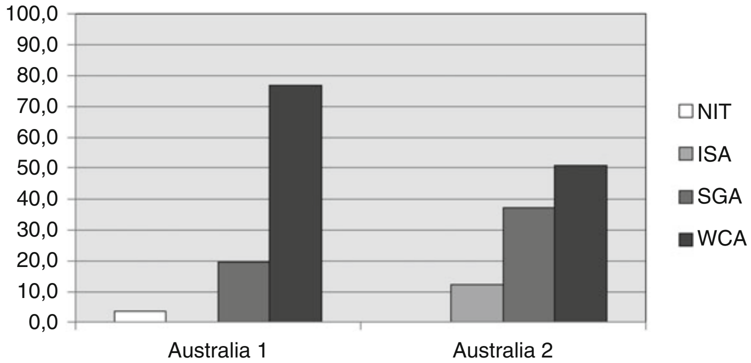

Fig. 4.3 Use of instructional time (percentage) by two Australian case study teachers

Two sets of graphs were used to probe the teachers' perceptions about variations in use of instructional time. The first set of graphs (Fig. 4.2) illustrated the use of instructional time by one case study teacher from each of the three countries; Australia (Country 1), Germany (Country 2) and Taiwan (Country 3). This set of graphs was used to probe teachers' perceptions about the reasons why the use of instructional time might vary between countries. The second set of graphs (Fig. 4.3) illustrated the use of instructional time by two Australian teachers. This set of graphs was used to probe teachers' perceptions of the reasons for variation in use of instructional time within a culture.

Interviews with a sample of the case study teachers revealed the instructional purposes they achieved using different classroom settings and the influence of context and their own beliefs on their use of the settings.

Factors Influencing Choices About Classroom Settings

When one of the Australian case study teachers (Teacher A3) was asked which of the graphs in Fig. 4.2 represented her teaching, she immediately identified the Country 1 graph as her teaching based on the high proportion of small group work. She explained that:

> Small group work is for students to have a practical and experiential … exploring the concepts. It helps build their skills, so it's really important that they're given an opportunity to investigate and discover … that child-centred investigating. So they are actually experiencing, … I have given them a context in the whole class introduction, so they kind of know what they are looking for, they know what the purpose of the activity is and then they explore and hopefully they in that process they are discussing with their peers and that is consolidating their understandings.

Teacher A3 notes the important relationships between classroom settings in that WCA is necessary to set a context and purpose for SGA. She also uses WCA for introductions to lessons, modelling and for sharing observations and explanations emerging from SGA. She explained that WCA is:

> … beneficial for modelling … so the students actually knew what to do with the materials that they were being provided, so that was a whole class, but then they move off and then they're in their small group. At the end of lessons I would bring everyone back in, they would share their experiences. So, they are sharing their experiences in their small group and hopefully having their academic discussion there and then they bring those ideas and we share as a whole class.

Teacher A3 uses individual student activity mainly for assessment tasks at the beginning of a topic for diagnostic purposes and at the end of a topic for summative assessments.

> … at the beginning [we would do] a mind map of what they might be thinking and their ideas about a certain concept and then we'd re-do that again at the end and you can see how the mind map has different threads and they have a deeper understanding of certain things and ideas and concepts within that.

The videos also showed Teacher A3 using ISA for reading comprehension tasks which were scaffolded using worksheets. Teacher A3 explained that:

> There's always an element of that independent work embedded in throughout, and I also have the crossover and integrating of language; so reading and comprehension and I've got resources that are Science and English combined so therefore I can go to that resource and then in our English session the students will do that independently.

Teacher A3 used a large proportion of SGA, and so, she was asked if there was something about her education philosophy, education system or the topic that influenced her frequent use of SGA. She explained:

> I guess there's a combination of a couple of things. Certainly my philosophy and my belief that especially in Science, students learn through doing and I think it's really, really important that they talk about things, they experience things then they discuss things and it's really important that that is done within a small group … We should be teaching Science like we do Science.

She explained that her use of SGA was not influenced by the topic being taught, however, she had been influenced by the professional learning she had undertaken as part of the *Primary Connections* program (Hackling et al. 2007) and by her initial teacher education that had emphasised the importance of small-group materials-centred activity work. To make the SGA effective she uses groups of three and develops a cooperative classroom culture supportive of group work and tries to ensure students understand that they have roles and responsibilities within the group. She noted that: "I don't have any steadfast way. I don't always have mixed ability, or same ability. I've even trialled and it worked beautifully, when we were doing forces, I had single gender groups and mixed ability. That worked really well".

When the two German case study teachers who co-taught a topic on forces (Teachers G1) were interviewed, they could identify the graph (Fig. 4.2) that represented their teaching. They noted the high proportion of ISA and explained that: "individual work, moments where students should write down, articulate there one's thoughts, alone and written down, their thoughts play an important role" in their learning. The German teachers considered active student thinking about science phenomena was a thread common to all classroom settings: "In whole class – thinking together, that was important". And, "small group activities are for hands-on activities, but small group activities are not only hands-on, also minds-on activities".

Teachers G1 and G2 from the German Case 1 could also correctly identify the graphs which represented an Australian teacher and a Taiwanese teacher. "Australia, I think this is Country 1 because that green (column – SGA), I think they are similar structured like America. The didactic tradition is more discovery learning. A lot of group activity, that is typical … I have sympathy for that".

When asked if anything had a strong influence on their approach to teaching science, the male Teacher G1 from the German Case 1 explained that the education philosophy of Martin Wagenschein (2010) had been very influential, and that talking about the core idea of a natural phenomenon was the way to learning. Students need to have the freedom to "be open to the process of learning and understanding" and that both teachers and students need to be passionate about problem solving. The female Teacher G2 from the same case study noted that: "the topic, the phenomenon is the most exciting thing, and the teaching strategy has to serve the understanding of the phenomenon". During WCA, Teacher G1 stated that the purpose was to allow students to "think together to understand something together" so that explanations could be co-constructed. Both teachers had a strong focus on supporting the individual student, to engage with phenomena and think through ideas and explanations, as they felt that this is the way to understanding. Analysis of classroom video demonstrated clearly that these teachers were prepared to give plenty of time to allow students to grapple with their thoughts and develop explanations for phenomena.

Although the Taiwanese cases appear to be characterised by a high proportion of WCA and fast-paced teaching, there is considerable variation between the cases with WCA ranging between 97 % and 48 %, and range of teaching strategies used within the WCA setting. One of the Taiwanese case study teachers (Teacher T2) explained that science teachers in Taiwan have an extensive curriculum to teach to their students, which limits the amount of time available to work on each topic. Teacher T2 explained that this required her to be a “strong manager of learning”. “In fact, it would be great if students can find answers by themselves. However, because of the limited time, I must specify to them how to do and what to observe”. Teacher T2 chose to omit some activities of which students already had experiences and to substitute recalling former experiences for real experiences in class. She focused on key concepts in the textbooks so that more time could be left for hands-on activities. She utilised whole-class formats for discussion rather than SGA because “Whole class discussions can save time.” She recognised the limitations of whole-class discussions in that: “you can only hear voices of some students who like to speak in class. Their voices give teachers a mistaken impression that they stand for the whole class. Actually, there are still many different ideas”. To compensate for this Teacher T2 tried to combine small-group discussions with whole-class discussions.

Discussion and Conclusions

Analysis of the data gathered in this study reveal complex inter-relationships between educational context and culture, teachers’ education philosophies and beliefs, and the choices made about use of instructional time, teaching strategies and instructional settings.

All of the teachers that were studied in the EQUALPRIME project were nominated by their peers as being experienced teachers of science that utilised good teaching practices. The teachers were seen as effective teachers within the cultures and contexts within which they worked. The video case studies showed that they implemented their teaching strategies effectively. Analysis of the case studies revealed that each teacher had a unique pedagogical fingerprint, a distinctive pedagogical repertoire and signature pedagogies which are reflected in the data reported about their use of instructional time and instructional settings.

Variation in use of time and pedagogical repertoires was hypothesised to be driven by two categories of variables. From ecological systems (Bronfenbrenner 1989) and socio-cultural (Gee 2008) theoretical perspectives it would be expected that the social, educational and cultural settings of the schools would broadly frame the approach to science teaching in that school. For example, culture would influence the roles adopted by teachers and expectations of parents about the importance of science would influence the extent to which it is represented in the school’s curriculum. Curriculum policy and curriculum resources specify what science should be taught and vary between cultures in the extent to which they specify how it should be taught. It would be expected that the impact of the broad cultural setting and curriculum policies of a country would be seen to some extent in all schools within that culture. Evidence for this is most clearly seen in the much higher mean WCA time in the Taiwanese cases compared to the Australian and German cases

(Table 4.2). The greater use of the WCA instructional setting by the Taiwanese case study teachers appears to be related to the extensive amount of science in the curriculum to be 'delivered' in the available time and the nature of the curriculum resources. Teacher T2 explained that the WCA setting was efficient in terms of getting through the content, in that ideas could be developed with all students at one time. Analysis of the video also revealed that the extensive range of high quality digital learning resources available to Taiwanese teachers supported them in providing rich representations of phenomena which could be interrogated by the class within a WCA setting.

The pressures of getting through the content and the availability of digital learning resources appeared to be much less in the German schools so the factors predisposing teachers towards WCA settings were less pronounced. Indeed, a broad cultural commitment to nurturing the intellectual growth of the individual, often referred to as *Bildung* (Fend 2008), also supported the greater emphasis on ISA and SGA instructional settings in the German cases.

The other class of variables expected to impact on the instructional approach are the educational philosophies, beliefs (Hashweh 1996) and identities (Connelly and Clandinin 1999) of the teachers themselves. Although the broad philosophical commitments of individual teachers are to some extent influenced by the cultural and curriculum setting within a culture, variation between individuals would be expected based on their personal beliefs and identities formed through their life experiences. The OECD TALIS study (2009) revealed differences between countries in teachers' commitments to transmissive or constructivist forms of instruction whist studies of individual teachers (e.g., Hashweh 1996) have revealed that those with social constructivist epistemological commitments use more student-centred approaches than those without such beliefs. Teacher A3 reported that her teacher education and further professional learning based on the social-constructivist inspired *Primary Connections* program had influenced her commitment to materials-centred SGA in which children can investigate and gain experiences with phenomena, and then through conversation with their peers, explore potential explanations for their observations. This commitment to working in small groups is reflected in the high proportion of SGA in Teacher A3's case and more broadly in the higher mean SGA time in the Australian cases compared to the Taiwanese cases.

There were distinctly different views expressed about the use of instructional time, which appear to be influenced by contextual and personal variables. Teacher T2 talked about the efficient use of time and of saving time, whereas Teachers G1 and G2 talked about making time available for thinking and giving time to students so that they could think through ideas. Teachers G1 and G2's commitment to giving time for individuals to work through ideas was reflected in the time they allocated to ISA in which students would think about a problem and write their thoughts in a journal. Analysis of video from the German case on forces also revealed that in whole-class discussions, individual students were given extended opportunities to explain their ideas, explanations and solutions to problems. This style of whole-class discussion was quite different to that observed in the Australian cases, where teachers attempt to engage as many students as possible in a discussion and the co-construction of an explanation, which tends to limit the opportunity for an individual student to develop an extended argument. The video from the Taiwanese cases revealed a third style of whole-class discussion in which there is frequent use of chorus answering (Clarke et al. 2013), and the discussion is much faster paced than in the Australian cases and the deliberately very slow paced German discussions.

The data gathered through these case studies reveal an alignment between the cultural setting, the epistemological beliefs and types of learning outcomes valued by the teachers, the academic tasks and teaching strategies utilised to achieve the outcomes, and instructional settings of the activities. For example, the German case study teachers worked in a school culture framed by philosophies of *Bildung* and more particularly of Martin Wagenschein and dialogic learning by Ruf and Gallin (Gallin 2010). They believed in the necessity of giving time to students for thinking and intellectual development, posed tasks as open and unstructured problems to be solved and made use of ISA and even whole-class discussions for individual student thinking. This alignment of instructional intention, task, strategy and setting maximised students' opportunity for learning the problem solving skills valued by these teachers. Similar alignments were also evident in the Australian and Taiwanese cases.

Analysis of instructional settings data from these case studies gives valuable insights into the practice of the teachers studied. Each of the teachers had a distinct and fairly consistent pattern of using whole class, small group and individual student settings, which gives students a sense of order and routine. The teachers' establishment of a 'ritual' organisation of the lesson helps to instil a sense of belonging and security, in the sense that students know what is expected of them. All our teachers did this well, which is a characteristic of these quality teachers. It was not possible in this EQUALPRIME research to relate the use of instructional time to effectiveness of practice and achievement of learning outcomes; however, all the teachers were nominated as being effective practitioners, which suggests that there are different ways of being effective both within and between cultures.

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Chapter 5
Inquiry Teaching and Learning: Forms, Approaches, and Embedded Views Within and Across Cultures

Hsiao-Lan Sharon Chen and Russell Tytler

Background

Inquiry has been a strongly advocated approach to teaching and learning generally and particularly in science for many years. The term has a long history in the ideas of key US educators such as Dewey (1996) and Bruner (1960). Schwab (1962) argued for a science curriculum that focuses on the syntactical as opposed to the substantive structure of the discipline of science: the way science ideas are posed, experiments performed, and data converted into evidence for new knowledge. Schwab's vision thus aimed at aligning science classroom processes more closely with the knowledge producing practices of science itself. This aim finds strong echoes with the recent PISA 2015 *Scientific Literacy Framework* categories of *Procedural and Epistemic Knowledge*.

How prevalent are inquiry approaches to teaching and learning science? Inquiry has been a strong theme in US curricula for decades and is represented in the current *Next Generation Science Standards* (National Research Council 2013) by the dimension of *Practices of scientists*. Inquiry also underpins a range of recent European Union science education projects. In the Australian Curriculum: Science (ACARA 2013) it appears in the dimensions of *Science as a Human Endeavour* and *Science Inquiry Skills*, the former including the way scientists work to generate new knowledge. In the *Curriculum Guideline of Science and Technology* (Ministry of Education 2013) for Grade 1–9 compulsory education in Taiwan inquiry has also been emphasised as important attitudes and a key skill of science competencies. Yet, despite this consistent advocacy of inquiry in national curriculum documents,

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inquiry teaching and learning has not proved easy to implement at system level. Osborne writes:

> Four decades after Schwab's (1962) argument that science should be taught as an 'enquiry into enquiry', and almost a century since John Dewey (1916) advocated that classroom learning be a student-centred process of enquiry, we still find ourselves struggling to achieve such practices in the science classroom. (Osborne 2006, p. 2)

What is inquiry, in science curriculum terms? One of the difficulties of talking about inquiry is the lack of specificity of what it can mean, in classroom terms. Inquiry in science has variously been interpreted through other lenses in advocating particular practices, such as hands on learning, discovery learning, problem based learning, the process approach, and student based investigative work. Ronald Anderson in 2002 discussed this problem of ambiguity in the term inquiry and described three distinct meanings of the term in the literature: scientific inquiry, referring to the diverse ways in which scientists practice to generate and validate knowledge; inquiry learning, referring to the active learning processes in which students are inevitably engaged, and; inquiry teaching, which is the main focus of literature around inquiry, for which there is no clear operational definition.

Anderson argues that inquiry is generally defined broadly as a reform pedagogy in opposition to traditional pedagogies and is taken to have a range of characteristics in relation to the teacher's role, the student's role, and the nature of student work. In Anderson's scheme inquiry pedagogies emphasise:

- For the teacher's role, a shift from 'dispenser of knowledge' to facilitator or coach to support students' learning;
- For the students' role, a shift from being a passive receiver of knowledge towards a more active, self-directed explainer and interpreter of knowledge;
- For student work, a shift from prescribed activities towards tasks where students play a more active role in decision making and reasoning to solve problems

In inquiry approaches such as Lawson's (1995) Learning Cycle, or Bybee and colleague's (2006) 5Es approach, a key characteristic of inquiry is that students explore phenomena and ideas before the teacher builds explanations, and that science ideas are discussed rather than transmitted as reified and static. Key differences with inquiry teaching as opposed to 'traditional' teaching relate to the relative responsibility of the teacher and students to introduce and explore ideas in the classroom community, and the degree of exploration and latitude allowed to students in investigating phenomena, and ideas.

In sorting through the many definitions of inquiry adopted in the literature and in projects, the Interacademies Panel International Working Group on Inquiry-based Science Education, in their report on *International Collaboration in the Evaluation of Inquiry-Based Science Education* (IBSE) programs (Interacademies Panel, IBSE Working Group 2011), identified what they saw as the key features of inquiry-based science teaching and learning:

> Students are developing concepts that enable them to understand the scientific aspects of the world around them through their own thinking using critical and logical reasoning about

> evidence that they have gathered. This may involve them in first hand manipulation of objects and materials and observation of events; it may also involve them in using evidence gained from a range of information sources including books, the Internet, teachers and scientists. (p. 4)

This is a broader definition of inquiry than is often advanced, one which emphasises developing independent and critical thinking but does not necessarily privilege student-initiated work, and one which could be seen as useful in defining a minimum set of inquiry characteristics.

Is inquiry teaching effective? Anderson (2002) reviews a number of meta-analyses of research comparing inquiry with traditional approaches and makes the point that while the results generally favour inquiry, there is little consistency in the results because of the problem of a lack of operational definition that would bring confidence to the comparison. A nuanced meta-analysis by Furtak et al. (2012) concluded that those aspects of inquiry that involved engaging students in generating, developing, and justifying explanations as part of science activities generally resulted in significant learning advantages compared to other aspects. This is consistent with a framework developed by Chi (2009) differentiating between types of overt activities undertaken by learners: active (students actively respond to the teacher or task as distinct from being passive where they simply absorb); constructive (students generate ideas or models); and, interactive (students dialogue, argue or justify, or jointly create ideas or models). Each of these is identified with a cognitive process, from attending, to creating, to jointly creating processes. There is evidence of learning advantages as activities progress from passive to interactive.

From this brief review, we conclude that inquiry teaching is a globally recommended teaching and learning approach, but that because it is often linked with other theoretical perspectives on learning and so differs in the way it is framed, it is ambiguously defined. The core element, however, seems to be that inquiry teaching involves an emphasis on students being actively involved in reasoning and exploring ideas, with the teacher monitoring, shaping and responding to students' ideas rather than simply delivering knowledge. It is often argued that what counts as inquiry teaching can be placed on a continuum, for instance from partial to full inquiry, or from guided to open inquiry, depending on the degree of responsibility allowed the learner as a result of the degree of closeness of scaffolding by the teacher. Despite the fact that inquiry teaching has proven difficult to implement at system level, there is substantial evidence that it is effective in supporting student learning, and that the particular feature of inquiry teaching that leads to the most substantial learning gains involves students interacting to develop and justify science ideas as a key aspect of the approach, consistent with epistemic practices in science (Furtak et al. 2012).

In the EQUALPRIME project we have detailed information concerning teaching and learning sequences of competent teachers who, broadly speaking, subscribe to inquiry perspectives on teaching and learning in science. Yet the circumstances in which they practise this are very different, in terms of system resources and constraints, and teaching and learning traditions relating to broader cultural factors. Based on the video-ethnographic analysis of the observed science classrooms, our aim in this Chapter is to develop case studies from teachers in the three countries teaching the topic of levers to explore the impact of local cultural and curriculum contexts on the framing of inquiry processes in these classrooms. The purpose of this analysis is to shed light on the core aspects of what one might think of as competent inquiry teaching in science; and the dimensions across which inquiry approaches can vary.

Case Studies of Inquiry into Levers

As is pointed out in Chap. 2, the broader social and cultural factors, such as government policy, school philosophy and curriculum priorities, shape the ways in which teaching and learning of science are transacted in different countries. Three case studies are presented here: two teachers, Ms Lennard and Mr Arnold, co-teaching a multi-grade class of Grade 4, 5, and 6 students (between 10 and 12 years old) at a reform-oriented primary school in Germany; Mr Roberts teaching Grade 3 in a government school in Australia; and, Ms Paulin teaching Grade 6 at a government primary school in Taiwan. Although they are teaching the same topic, the school curriculum organisation is different in each case, with varied emphases, and the teachers are distinctive in their ways of engaging students in scientific inquiry.

Inquiry Through Peer and Teacher Dialogue in Ms Lennard and Mr Arnold's Class, Germany

In the German case study, teachers are committed to the approach of Dialogic Learning (Ruf and Gallin 2005) that through dialogue they can move from individual conceptions to a shared scientific understanding of the key characteristics of a problem. In their exploration of the phenomenon of the lever in the context of a unit on forces (Table 5.1), Ms Lennard and Mr Arnold started with a question presented in the form of a 'core idea' through deliberately presenting a photo of a high-rise building with a precarious makeshift work platform suspended from the roof and held by two steel rods and a pile of sandbags, in a lever arrangement (See Fig. 9.5 for a representation of the photograph).

In the initial stimulus lesson there was no overt mention of levers or even, initially, what students should focus on in their thinking. They wrote down their thoughts and comments in a personal learning journal, referred to as a 'travel diary', which is used as a medium for dialogue between the students and teachers and sometimes, as in this case, also between the students. They then participated in a 'dancing chairs' activity to share these ideas. In this process, students leave their journals open on their desks and move to the seat of another student. They read that student's ideas and hypotheses and enter their comments in his or her journal. In this

Table 5.1 The first four lessons of the German lever unit, focused on the gondola

Lesson 1:	Children are asked to interpret a photo of a building with a strange construction (WCA)
Exploring children's interpretation of question relating to force	Sharing ideas through 'dancing chairs'- children write thoughts and comment on others' (ISA)
	Gathering and organising ideas – representation of individual ideas on board, sorting into categories (WCA): feelings, observation…
Lesson 2:	Refining the core question – teacher selects a journal entry
	Discussion – 'Why does the gondola not fall down?' (WCA)
	Children reflect and respond in their journals 'What makes the men so sure they will not fall down?' (ISA)
Modeling gondola to explore lever principles	Groups discuss and agree on one statement to present (SGA)
	Gathering and organisation of ideas on board (WCA)
	Experimental exploration of ideas – students construct a model to test conditions for a gondola to be supported
	Ongoing recording of results in journal and their changed thinking
Lesson 3:	Discussion of selected idea from previous day's journals (SGA)
	Gathering and organisation of class ideas in small groups (SGA)
	Groups report and discuss findings (WCA)
Exploring the relation between weights for the lever	Exploring a design problem – 'Design a construction that will hold 40 bricks.' (SGA)
	Students are asked to record their experience in their journal and include a drawing of their construction
	Teachers support representation of situation – provide advice on board concerning drawing and take pictures of constructions
Lesson 4:	Gathering results – photos of children's constructions discussed (WCA)
	Generation of explanatory ideas – children encouraged to speculate (WCA)
Drawing ideas together and relating to levers generally	Children record their thinking in journals (ISA)
	The class then begins a further inquiry cycle that extends for a further three lessons. Children are asked to test their hypothesis using a wooden board and wooden bricks on a desk placed in the centre of the classroom while the others watch (WCA)
	Teacher collects data in a table (blackboard), and students are asked to reproduce results with bricks placed on their desks (SGA)

WCA whole class activity, *SGA* small group activity, *ISA* individual student activity process many ideas are discussed in the classroom simultaneously and all students are obliged to come up with ideas, possible solutions and answers to their questions about the phenomenon. These ideas were then gathered and organised on the board in a whole class discussion.

In the next lesson, Ms Lennard and Mr Arnold displayed a selected journal entry and also a drawing that abstracted the key features of the situation to the whole class for discussion. In the course of lengthy verbal and written discussions, followed by hands-on activities, a joint understanding of the phenomenon emerged. This general theorem remained in the students' own terminology during the first few lessons; technical terms were only added by Ms Lennard and Mr Arnold towards the end of the unit in line with the teachers' philosophy whereby students must first grasp an idea before they can learn to express it using correct scientific terminology.

Students again recorded and shared ideas in groups that were then gathered and discussed in a whole class situation. Following this they built a model of the situation and explored the relationship of weights and position that could balance a gondola. Further writing and sharing of ideas activity led to a more focused challenge investigation the following lesson where students tested the minimum number of blocks needed as counter-weights to balance a small paper gondola with 40 wooden bricks over the edge of the desks. Figure 5.1 shows a typical investigative situation while an example of a student's journal entry from the second day is given in Fig. 5.2.

In the following short excerpt of the fourth lesson in this unit, the students were asked to compare photographs of their construction efforts in the previous lesson and to report their experiences (Fig. 5.3). Several students gave lengthy answers referring to personal experiences and also to the photographs on the blackboard. The teachers gave shorter feedback and directed the discussion. In one case a girl

Fig. 5.1 Testing the lever principle

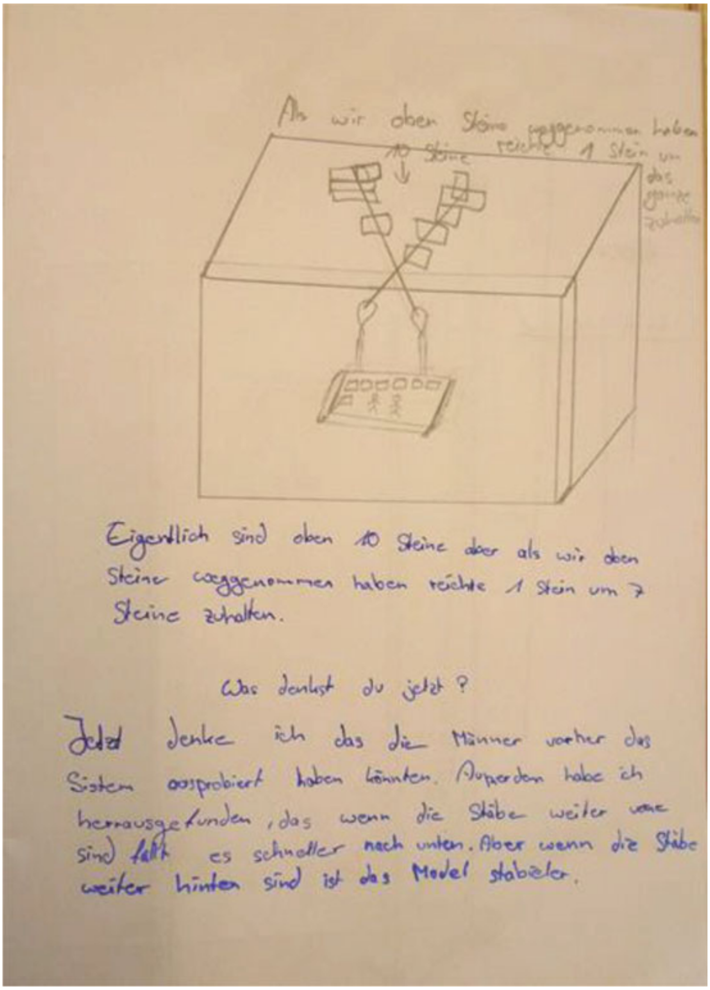

Fig. 5.2 A student's journal entry
English Translation of the German text:
Originally there were ten stones. But when we removed stones, one stone was enough to carry 7 stones
What do you think now?
Now I think the men may have tested the system beforehand. Beyond that I discovered that when the stones are placed in the front, it (the gondola) falls more easily. But when the stones are placed in the back, the model is more stable

Fig. 5.3 A child spontaneously testing a hypothesis

referred directly to the comment of a boy, asking him for clarification. Meanwhile another girl took a pen out of her pencil-case, placed it halfway over the edge of her desk and appeared to test the lever principle using her hands (Fig. 5.3). Having apparently confirmed her hypothesis, she raised her hand and the teacher let her share her discovery with the class.

T1:	*Ah, yes. Any similar experiences with where you placed the stones* [*the counterweights*]? *Neil*?
Neil:	*We also placed them right in the back, because in the front, well the fact is that in the front there is much more weight. But in the back it is somehow better because for example* [*if someone*] *wants to loosen the nut of a screw it is really difficult with a small wrench. And one can for example insert a metal pole and then, because it is longer, it is easier to do this as it is also easier for the poles to hold when it* [*the counterweight*] *is further back.*
T1:	*Ok.*
T2:	*Aha.*
T1:	*Noni*?
Noni:	*One could also, if one does this* (*demonstrates with pen – see Figure* 5.3) *if one presses here, then it won't come up easily. But if one presses here* (*she presses down on the end of the pen jutting from the table*), *it does so easily.*
T1:	*Yes. Another experience*! *Yes. Dennis*?

Dennis: *This is also, for example like with the lever principle. If, for example, one wants to lift a tree with the help of a shovel and one digs it deep into, into the earth and then lifts it, I mean puts it underneath, then it works better than if one puts it in only slightly and then tries to "lever" it out*
T1: *So I gather the principle "further away" from your words?*
Dennis: *Well, not exactly. So that not much of the beam is visible at the end because otherwise it would come up.*
T1: *Patricia?*
Patricia: *But (to Dennis) – that is really strange! The stones [the counterweights] are at the back after all. And if it still works so well and there are more stones in the gondola than up then the stones could also lift it up. And then it would also not hold so well.*
T2: *Which picture illustrates clearly what Dennis was just trying to say?*
Patricia: *Well, he just said that when one wanted to uproot [lit. lever out] a tree one places the shovel inside and then one tries to lift it at the back. And if we take the stones here and the poles are up to here and the gondola is hanging from the poles and there are stones inside, then they could also lift it a bit easier somehow.*
T2: *Where – to stay with Dennis's picture – would be the front and where would be the back, the way you understood it now?*
Patricia: *Well the back of the shovel and the back…*
T2: *The back of the shovel. And in your example with the stones?*
Patricia: *At the back of the poles. In that case the gondola could pull down what is on top at the very back, because it is heavier.*

In the sequence of events over the first four lessons in Ms Lennard and Mr Arnold's class, there is a continual shift in class organisation (Fig. 5.4) from individual student activity (ISA) to small group activity (SGA) to whole class activity (WCA) and back to whole class and back as ideas are generated, shared and refined.

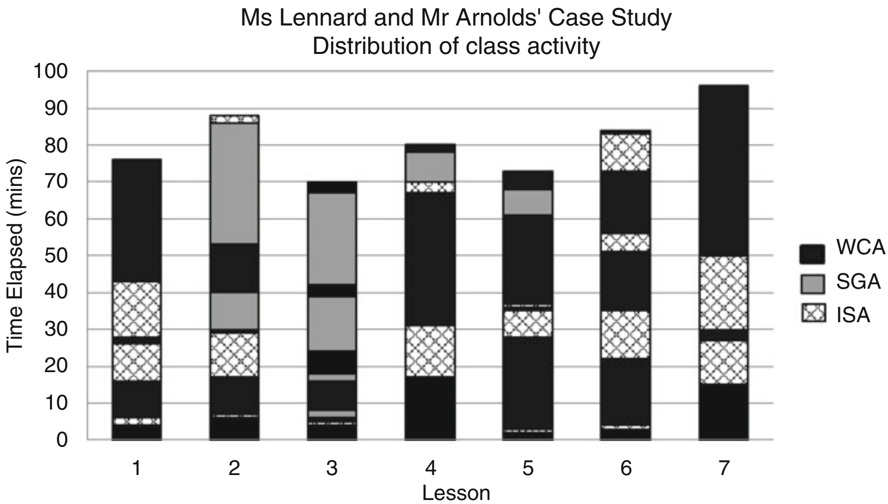

Fig. 5.4 Class organisation in Ms Lennard and Mr Arnold's lever sequence

We can see a cyclic movement from posing or refining the core problem, student generation of ideas, communicating, gathering and organising ideas, experimentation, recording results, once again gathering and refining ideas, to start afresh on the cycle. It involves back and forth interaction of talk, writing and hands-on experimentation to build explanation through claim making and justification processes. It shows fascinating 'joint dialogues' as characterised by Chi (2009), where students build and elaborate on peers' contributions, as well as explain and defend their ideas in a co-construction sequence.

Also, in subsequent lessons a similar process is followed to explore the ideas underlying the seesaw, with students initially speculating on the position of blocks on a beam in class to make it balance, to an outside activity where students use levers to lift each other, to an exploration of the lever arm relations under the condition of balance. Strictly speaking, the class never quite reached a formal expression of the lever arm law. However, as Ms Lennard explained in a pre-unit interview "science for us has less to do with formulas and studying principles, but rather with a process of understanding. There is a common subject matter, the phenomenon, which needs to be explored. Our aim is that the children experience, understand this and that we can tell that they have understood something because they can consciously change parameters in order to change the impact of force. I mean, extending the lever arm or force arm."

Basically, in Ms Lennard and Mr Arnold's class, the guiding and refinement of student ideas towards scientific ideas is achieved not through the imposition of ideas by the teacher but primarily through the circulation and refinement of students' ideas through: (1) the strategic selection of student generated ideas that are productive in moving the thinking of the class forward, (2) the organisation of student ideas to clarify the dimensions of the ideas, (3) the introduction of representations that refine the problem, such as a drawn abstraction of the gondola lever elements that focus attention on the core question, and (4) the questioning style in whole class discussion which focuses on clarifying and extending students' input (see the discursive moves analysis in Chap. 6).

Inquiry Through Teacher Elicitation and Dialogue with Constructive Activities in Mr Roberts' Class, Australia

The second case is that of Mr Roberts, a specialist science teacher in a suburban school in a major Australian city. The class is Grade 3 and Mr Roberts takes them once a week for science. His main theme for the term is forces and motion, and in this sequence he taught about levers for 25 min of one lesson, followed by a 13-min sequence the following lesson. This 40 min sequence is thus much shorter than for the German lever sequence and so makes fewer demands on achieving specific knowledge of the scientific principle of levers. The sequence of events is shown in Table 5.2.

Table 5.2 Mr Roberts' two lessons on the lever

Lesson 1:	Introduction of principle of lever with balance (WCA)
	Hands-on exploration of role of lever arm and load for balance (SGA)
	Introduction of terminology: fulcrum, load, effort and engaging students with lever challenge (WCA)
Introducing and exploring the lever	Experimental exploration of design problem: 'Find the position of the fulcrum for maximum height of catapult'
	Gathering of results and explanation of lever arm relations
Lesson 2:	Extension of lever principles to wheelbarrow through questioning (WCA)
	Extension of lever principles to chopsticks and presentation of challenge (WCA)
Extension of lever principles to other situations	Hands on exploration of operation of chopsticks (SGA)
	Challenge race using chopsticks (SGA)
	Final explanation of chopsticks as lever (WCA)

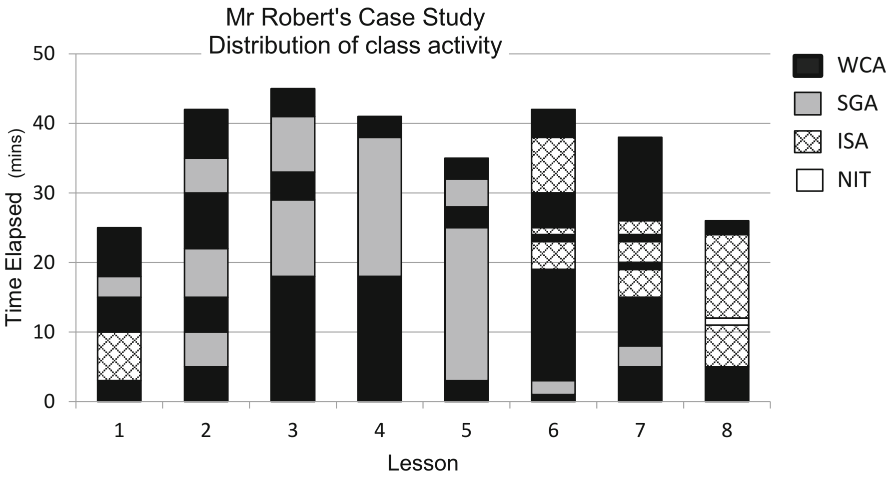

Fig. 5.5 Class organisation in Mr Roberts' lever sequence (*NIT is non-instructional time >2 mins*)

As with the German sequence in Ms Lennard and Mr Arnold's class there is a back and forward movement between whole class and small group discussion and investigative hands-on activity. There is, however, much less emphasis on individual student writing than in the German case. The breakdown of classroom organisation across the lever sequence is shown in Fig. 5.5.

Mr Roberts' main approach to inquiry teaching is to support student learning and engagement through hands-on activity experiences. Generally his sequencing for each task includes: (1) a whole class demonstration activity involving probing and challenging student ideas, (2) small group or individual challenge activity during which he circulates, supports students and further probes their ideas, and (3) a whole class discussion in which he draws on students' thinking to move them to a scientific explanation. One could interpret such a sequence through the 5Es model as 'Engage', 'Explore' and 'Explain' (Hackling et al. 2007). The final explain phase sometime segues into a further activity which could be taken to be an 'Elaborate' phase.

Mr Roberts begins by balancing a short 15 cm wooden plank on a small wooden piece.

Teacher: *This particular plank, Seb how would you describe the plank?*
Seb: *Balanced.*

Mr Roberts then puts a block on one end to unbalance the beam.

Teacher: *Balanced. What do I need to do to the plank Gary to make it balanced?*
Gary: *You pack some more to the other end.*
Teacher: *Same weight to the other end. Colour important?*
Student: *No.*

Mr Roberts puts a block on the other end.

Teacher: *So it's balanced.*
Student: *Roughly.*
Teacher: *Roughly. Why only roughly?*
Student: *Because sometimes depending sometimes on the colour it might put more weight on the block.*

Mr Roberts then moves one of the blocks closer to the fulcrum.

Teacher: *We need to test that. … If I put the block here… it's not balanced. So what do I need to make this balanced? Sean…*
Sean: *Well you've got to move that red brick back to… right at the end.*
Teacher: *Is that the only way I can do it?*
Sally: *No, move the yellow brick to the centre.*
Teacher: *Any other way I can do it?*
Sally: *Add another brick to the red one.*

Mr Roberts puts a further block on top of the block nearest the fulcrum, then another. It is still not balanced but Mr Roberts now announces the task.

Teacher: *Relax; you're going to be doing this, not me.*

He describes the challenge:

Teacher: *A weight. We'll come back to it. Now I'm not going to be generous to you. Your challenge is to balance the beam on the silver bit of metal… balance means balance. Now I'll let you into a little secret, no one has done it yet. Sorry not a single soul. But it is the Grade 6s so I guess that explains a lot.*

Students then explored, singly, combinations of the number and positions of blocks to try to balance the beam. They varied both the number of blocks, and the distance from the fulcrum.

When Mr Roberts gathered them back on the floor, he did not go over their findings, but set up another challenge exploring the lever as a catapult. He first established the language of fulcrum, load, and effort, and then introduced the catapult

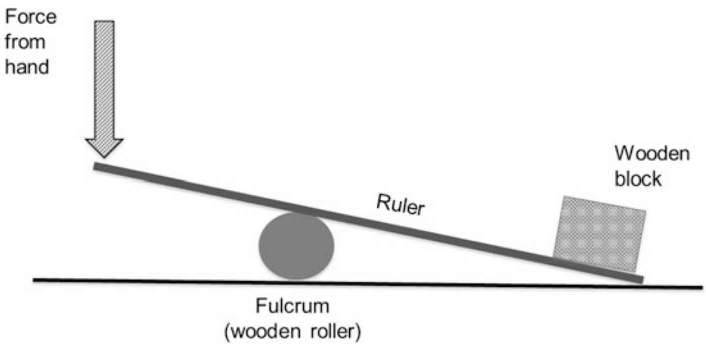

Fig. 5.6 The catapult as lever

(sitting a ruler on a small wooden fulcrum) and the effect of changing the fulcrum position (Fig. 5.6).

Teacher: *Nick, if I apply a force here, what will happen to the block? Gary… if I apply a force here, what'll happen to the block?*
Gary: *It'll go up.*
Teacher: It'll go up. Will it go up further with the fulcrum there or there? What do you think?
Student: I think if it's closer to the block it will go higher.
Teacher: So when it's closer to the block, it'll go higher. Why's that?
Student: When it's out cause then it has… when you push it down you have more room to go up…

The challenge involved students seeing where the fulcrum needs to be to give most height for a catapulted block.

Teacher: *more room to go up. We're going outside now. You're taking one fulcrum. One beam. One block. And I want you to test Lena's idea, that wherever you put the fulcrum, the block could go higher. So if I were to do… interested in how high the block goes.*

As students investigate, he circulated and encouraged the students to vary the fulcrum position. He probed their ideas.

Teacher: *Righto. How can you make it go higher Harry?*
Harry: *I know now.*
Teacher: How… How can you make it go higher? (The boy demonstrates) Right so what made it go higher?
Harry: I put a smaller area, a smaller target, so that it gets more propulsion. And I can make it go even higher.
Teacher: Why? Other than a sore finger. Why?
Harry: Because I put it there which means it gets more momentum.
Teacher: More momentum. (Acknowledging the idea)
Harry: It's closer and it means there's more power. It has more power to go to the end.
Teacher: Righto (Mr Roberts then moves on to another child)

In the class discussion Mr Roberts represented the lever layout on the board and asked students to report which position of the fulcrum gave most height. He got

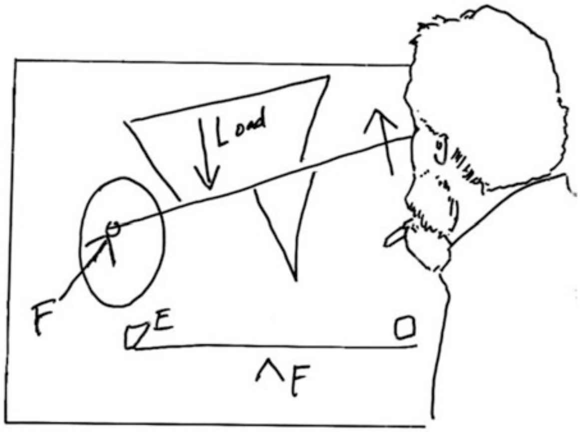

Fig. 5.7 Mr Roberts compares the lever structure of the catapult, and wheelbarrow

inconsistent responses, and ran short of time. He ended the lesson by describing how the distance travelled by the lever arm is the key to explaining differences in height reached by the blocks.

Teacher: *What we hit it with a force there the block goes up. The distance the block goes up seems to depend on where the fulcrum is. I expected it would be this one because … this one … you've got the block there, the distance that the beam can travel is longer than when the beam is there. The further this can go down here the further it can go up there (drawing arrows).*

The students then speculated on the principles of the lever based on their own experiences. They argued that weight and thickness of the beam make a difference.

Harry: *I thought… you know how you did that in the middle, well if you put the block down at the same time, if you've already got one down… you've already got one on, and then you put on another one, it's going to take off more weight, so that's why it goes down.*

Following this, in the next lesson, Mr Roberts discussed the principles of the wheelbarrow. He first asked students to interpret where the fulcrum, load and effort are. Then he used the sketches to contrast the position of the fulcrum with respect to load and effort, compared to the beam and catapult (Fig. 5.7).

Teacher: *Any other thoughts? Here where you hold it. There's the effort. How is this different to this? How are they different? Seb, look at them, my beautiful drawing…*

Seb: *The wheelbarrow … [inaudible]…*

Teacher: *Les…*

Les: *… [inaudible]… is like it's just wood and the wheelbarrow is connected to the wood.*

Teacher: *Think of the FEL. Can you see any difference between the two? Any difference… what do you think Josh, any difference? Yes Mike…*

Mike: *The load is in the middle.*

Teacher: *The load is in the middle here, the fulcrum is to one side. Here the fulcrum is in the middle. So the fulcrum load and effort do they have to be in the same order?*

All: *No.*

Mr Roberts then introduced a similar sequence of questions with chopsticks as an example of levers, with students identifying where the fulcrum, load and effort are.

Teacher: *Where's the fulcrum? Yes…*
Student: *Just in the middle where you're holding it.*
Teacher: *In the middle where I'm holding it. Where's the load?*
Student: *In the middle.*
Teacher: *Alan…*
Alan: *Marble.*
Teacher: *Marble is the load. Tricky, where's the effort? Yes Le…*
Len: *The hand.*
Teacher: *I think it's the hand 'cause there's nothing up here. And my hand when I move it is what's holding it.*

The students then practiced using chopsticks as Mr Roberts circulated and helped. At one point he stopped the activity to hold up his hand to demonstrate in a deliberate manner.

Teacher: *When I was using the chopsticks my top finger is pushing down. So I'm wondering whether that's going to be the effort. So I've got the load and maybe my top finger is the effort and my thumb and middle finger seem to be the fulcrum is, it swivels.*

It was obvious that Mr Roberts was good at engaging students' attention in learning. In interview, he placed great emphasis on the need to engage students if they are to learn. He did this through keeping them active with tasks that involved challenge, sometimes competition, and humour.

> I find it really hard to teach a child if they're not happy. So if you've got them happy and you've got them engaged, I've got a chance. If I haven't got them engaged, and they're dead bored, or they're unhappy, my chances are limited. So it doesn't have to be fun but it has to be such that they're enjoying it.

He is very attuned to exploring students' ideas, and uses their responses and his observations of their activity to probe their conceptions, and to engage them in classroom discussion that moves them forward.

> I look for their eyes. I'm looking for the feedback from there, and the only way I'm going to get the feedback from them, was talk to them. Yeah listening, looking, and the questioning is me talking to them.

In the analysis of discursive moves in episodes of Mr Roberts' (see Chap. 6), he was very strong on eliciting and acknowledging students' ideas, getting them on the 'table' in order to work with them and move them towards scientific views. He is very skilled at probing students' ideas then using talk to shape them towards scientific conceptions.

A noticeable aspect of Mr Roberts' practice is the lack of writing either by himself or by students. Almost the entire video sequence involves only talk and physical activity, and there is little re-representation of students' or scientists' ideas in written text, diagrams, models or graphs and tables. Inquiry for Mr Roberts involves active exploration and guided discussion. Tying ideas down through diagrams or models, or refining and extending ideas through multiple instances, is less of a priority than in the Taiwanese sequence in particular. It is also not typical of the other EQUALPRIME cases.

Inquiry Through Teacher Enacted Instructional Dialogues in Ms Paulin's Class, Taiwan

Within a culture of efficiency and competition, teaching and learning science and other subjects in most schools in Taiwan, follows a school-based unified teaching schedule, which is framed by the national curriculum. It is therefore quite impossible to conduct open inquiry that encourages student-directed learning as exemplified in the German case study. In order to keep up with the teaching schedule and to meet the curriculum guidelines, in most primary science classrooms students undertake largely teacher-controlled learning activities where they are expected to learn scientific reasoning through structured teacher guided inquiry. The third case is that of Ms Paulin, a specialist science teacher in a medium sized urban public (government) primary school in Taipei. The class is Grade 6 with 24 students (13 boys and 11 girls) and Ms Paulin teaches the class three 40-min periods a week for science with two consecutive periods on Monday and one period on Friday. The observed unit is on Simple Machines over 8 weeks (21 periods) of teaching on the principle, function and application of levers, force, wheels and pulleys. The first seven periods are on the themes of levers and force, and the sequence of instructional events is shown in Table 5.3.

Based on her science expertise and rich teaching experience, Ms Paulin is very well-organised in her instructional plan and is able to demonstrate a kind of interactive instruction that is both inquiry-oriented and highly guided. The breakdown of her classroom organisation across the first seven periods of the lever sequence is shown in Fig. 5.8.

Because she knows the possible misconceptions students might have, she is able to construct her classroom activities and discussions in a flow of dialogue with clear guidance, supporting materials, and scaffolding questions to engage students in learning and to clarify their thinking of scientific concepts effectively. In Ms Paulin's teaching, she always starts her class with eliciting students' prior knowledge or experiences to prepare students' mental readiness for the learning of new concepts. For example, she started the Simple Machine unit by having students write the Chinese characters of machinery—機械and to probe their ideas about machinery and then to guide them, through displaying several machinery objects, to identify the features of machines as well to verify their initial thoughts about machines. In the next lesson, after reviewing and discussing the possible false ideas and misconceptions of machinery again, Ms Paulin set the discursive platform for the learning of lever principles by linking to students' experience and experimenting with the

Table 5.3 The first four lessons of Ms Paulin's simple machines unit, focusing on the lever

	Period 1
Lesson 1:	Recalling students' impressions of, thoughts on 機械/machines (WCA)
Exploring the definitions and types of simple machine	Discussion on the features of machinery (SGA)
	Presentation of group discussion results (WCA)
	Showing mechanical items for students to observe and to relate (SGA)
	Discussion on group findings and definitions of simple machine (WCA)
	Students identify functions of a variety of machines (ISA)
	Period 2
Lesson 2: (Double lesson)	Review L1; Recalling students' experience of playing 'seesaw' (WCA)
	Students experiment with simple catapult, class discussion (ISA-WCA)
	Experiment & discussion – relations of force and pushing point (SGA)/(WCA)
	Period 3
Exploring the concepts and structure of the 'lever' and related terms	Review; discussion of the characters, concepts of 槓桿/;/lever (WCA)
	Q&A – representing lever components and structure – Q&A (WCA)
	Experiments on the relations of lever constituents (SGA)
	Discussion on findings with demonstration- moving a heavy object with least force (WCA)
	Period 4
Lesson 3:	Review terminology/constituents of lever with PPTs (WCA)
Exploring the principles of lever balance	Introducing devices used for measuring weight force (WCA)
	Introducing devices used for measuring weight force (WCA)
	Experiment on lever force-distance relations (SGA)
	Discussion on findings and record their results (WCA)/(ISA)
	Period 5
Lesson 4: (Double lesson)	Review L3 findings and summarising lever principles (WCA)
	Students read instructions in workbook and add notes and comments (ISA)
	Experiment on further steps of balancing the lever by following instructions in the workbook (SGA)
	Discussing the findings using principles of lever balance, students write down answers and comments (WCA)/(ISA)
	Period 6
Exploring the functions and applications of lever	Discussing functions of and relations b/w effort & resistance arms for different tools (WCA)
	Students use lever principles to interpret different tools. present & discuss (SGA-WCA)
	Experiment and discussion of lever principles of lever using workbook questions. (SGA)/(WCA)

Then, Period 7 involved further reviewing activities of lever principles, functions and applications to prepare students for learning about pulleys

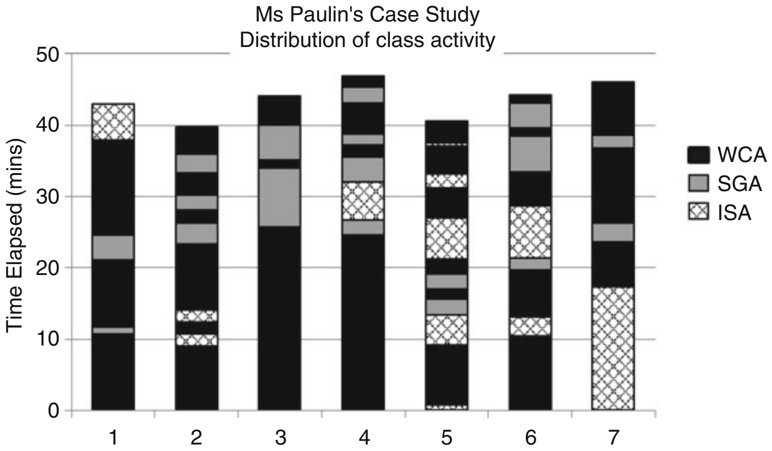

Fig. 5.8 Class organisation in Ms Paulin's lever sequence

seesaw. She gave clear instructions and expectations that conveyed to students the kind of scientific thinking they must engage in during the course of the inquiry.

Teacher: *The machine's characteristics we discussed last time are not wrong, they are just not complete enough.… So, from now on, we have to observe more, to think more about machines. We have to think that, Hey, is this a machine? What is it for? What is the benefit? Why did people invent it? When you see machines around, please do pay more attention to them and think more about them. Then you can share with us when we need more examples in the follow-up lessons. Today we are going to introduce machines formally. Last time someone said that machines are composed of many…?*

After discussion with students about the components of simple machines, Ms Paulin then delivered transitional instruction for the lesson to learn but made no mention of lever. Through her guided inquiry she pointed students towards recognising their prior learning made them aware that they were building on the prior learning and real life experience.

Teacher: *OK! I will introduce some small components one by one which constitute the complicated machines. What are the characters of those components? What can they do for us? You will get to know each of them gradually. Just as I said before, you must become familiar with every small part of electromagnets such as the electricity, the magnet, the electromagnet, and realise the principle of magnetic mutual repulsion and attraction, then what can you make?*

Student: *A toy.*

Teacher: *And what can this toy do?*

All: *Swing.*

Teacher: *It is repulsion force or attractive force that makes it move. OK, so you must understand all these small parts. Now, today I will introduce the first one. I won't tell you its name. I am not telling the name of this machine now. Let's think first. Have you ever played on a seesaw?*

All students were excited.

Teacher: *Ok, please tell me. Please close your eyes for ten seconds and think of a seesaw from your memory.*
Teacher: Are you ready?
Teacher: Ok. Now tell me what does the seesaw look like from your impression? What components does it contain?
Student: One horizontal beam and one vertical object.

Heated discussions going back and forth and many terms popped out from students such as pivot point, receiving force point, effort point, force, and so forth.

Teacher: *Ok, what else does a seesaw have*? *What is the main structure of a seesaw*?
Student: *Lever*.

Hearing the answer, rather than shifting immediately to an explanation of the lever concept as might happen with traditional teaching approaches, Ms Paulin continued leading the discussion on the structure of a seesaw and preparing students for the experiment of establishing the relations of forces in a lever to distances. Until the second period of the lesson, Ms Paulin pointed out the meaning of playing with a seesaw in relation to the learning of the simple machine, the lever. She began with questioning students about the originality and the hieroglyphic part of the Chinese characters 槓桿 to help them capturing the unique attributes of a lever while recalling the invention and evolution of levels. She then probed further discussions on the constituents of a lever by referring to a picture of a previous hand-made seesaw tool (Fig. 5.9) and proceeded with a force measurement experiment on finding the relations of fulcrum, application force point and resistant point.

Throughout the instructional process, Ms Paulin applied various representations (pictures, actual tools, multimedia resources), analogies, embodied demonstrations and guided experiments to help students comprehend the structure and principles of a lever and be able to use correct scientific language (terminologies) to describe the lever principles and the relations between related constituents (e.g., see Figs. 5.10 and 5.11).

More importantly she created gradually more challenging exercises to engage students in applying the language and concepts of lever principles in more complex situations, moving from learning the components and structure of the lever to recognising the relations between lever forces and arms, to understanding the principle of lever balance, and to appreciating the functions and applications of levers in a range of real-life situations.

The following excerpt from the second part of Lesson 2 provides an example of how Ms Paulin generated a step-by-step inquiry flow composed of a series of verification questions generated from and reacting to students' quick and short responses. She constructed a series of various types and modes of representations to introduce substantive concepts of the lever during the learning journey using questioning. She also devised modes of assessing students' understanding of the concepts both during the inquiry and in the following experiments and activities.

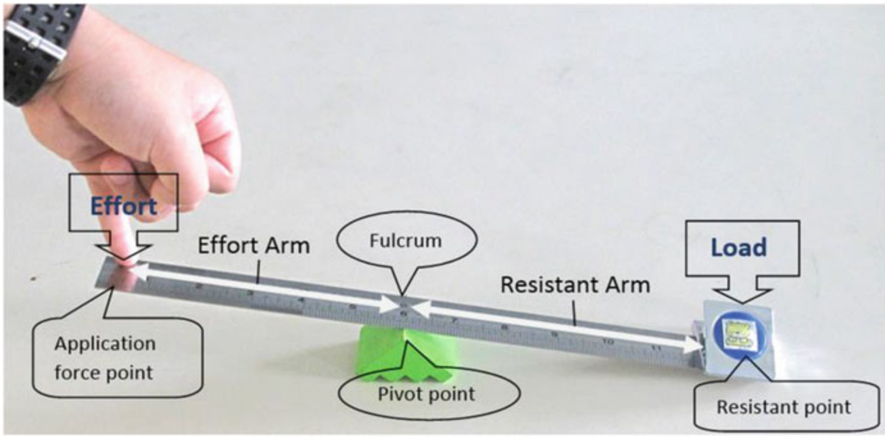

Fig. 5.9 Lever structure

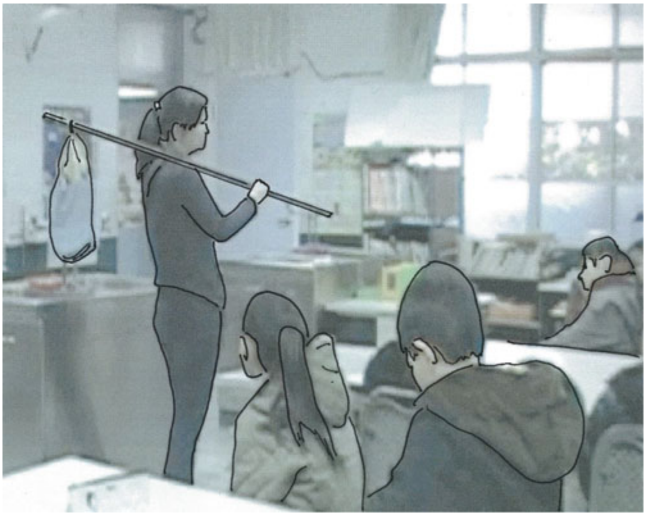

Fig. 5.10 Ms Paulin guiding the discussion on the relations between forces and arms through embodied demonstration

Teacher: *Ok, have you remembered all the eight terms? What is the reason human beings invented the lever? Is it just for playing seesaw?*
Student: *to carry stuff! To carry stuff.*
Teacher: *For moving stuff.*

Ms Paulin took a long stick which had a bag hanging on the end and then walked to the student nearby to borrow things to put into the bag.

Teacher: *Ok, please observe the motion that I am doing! Is it related to a seesaw?*

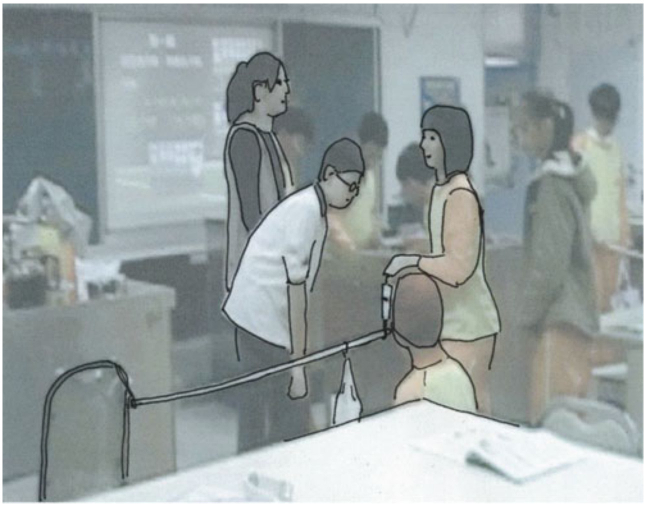

Fig. 5.11 Students exploring the relations between forces and arms, through moving the load and measuring the force

Ms Paulin leaned to one side and put the long stick on her shoulder. She held the front end of the stick and the bag hung at the back end of the stick. The teacher positioned the long stick on her shoulder so that it was parallel with the structure of the seesaw demonstrated on the table (Fig. 5.10).

Teacher: *Is it similar?*
Student: *It is quite so.*
Teacher: *So it is enlarged, right? I'll give you a test! And see whether you've truly understood or not! Now I ask you a question. Here is a stick and there is a force supporting it. Where is the supporting force point for this stick?*
All: *The shoulder.*

Ms Paulin shrugged her shoulder repeatedly.

Teacher: *I'm supporting it with my shoulder*, *right*?

The discussion goes on....

Teacher: *Supporting point, and what can it be simply called?*
All: *Pivot point!*
Teacher: *Ok, next, please tell me, where am I applying the force? Where am I controlling*?

Ms Paulin beckoned with her palm which was holding the stick, and then lifted-up the stick back and forth several times.

Student: *Hand*.

In the discussion, constantly referring back to the previous seesaw experiment, students were able to relate the hand as the application force point/the effort, the bag as the resistant force point/the load, and to point out the effort arm and resistant arm and so forth.

Teacher: … *Are they the same*?
All: *They are different. (Students thought the question was "Are the effort arm and resistant arm the same?")*
Teacher: Are they the same?

Ms Paulin pointed to the seesaw teaching aid on the desk and the long stick on her shoulder.

All: *They are the same.*
Teacher: They are the same! So you can see, a lever is not invented only for fun like a seesaw, though it is interesting. Actually, what was it invented for in the early days?
Student: Carry stuff.
Teacher: To move heavy objects. Please tell me, will the weight of this heavy object change?
Student: Yes.
Teacher: If I use a better designed lever, will the 5 kg object change to 0.2 kg?
All: It is impossible!
Teacher: It is impossible! But is that possible if I change the distance here, (Ms Paulin moves the long stick back and forth on her shoulder.) then I can apply very little force to lift up this heavy object?
Student: It is possible.

Then Ms Paulin stopped her demonstration and shifted the embodied exercise to students. Before doing that Ms Paulin again tried to clarify possible misconceptions by linking to the proper writing of the Chinese term.

Teacher: *OK*, *now I will show you something else and we will not play seesaw any more. Now*, *it is your turn to carry the heavy object. Please write* 槓桿(*lever*) *in the air. Watch carefully*! *Don*'*t write it back to front*! *From left to right*! *Write* 槓桿. *That*'*s right*! *Many of you may get confused and write the word as* 槓杆. (Ms Paulin writes the wrong character 杆 on the blackboard.) *It* (槓桿) *is a scientific term. It has been a unified term used by scientists*, *although* 杆 *also means a long stick*.

Ms Paulin wiped out the wrong word to avoid students mistaking it.

After the clarification of the characters, a student was invited to operate the stick acting as a lever and the discussion continued on how to use the least effort to move a heavy object. Figure 5.11 shows students exploring, with a force-measurer, the force needed to support a load at different positions from the fulcrum.

Again, we can see very clearly, in her step-by-step guided question and answer type of exploration, Ms Paulin wrestles a lot with the wording and embedded concept of her inquiry questions, prioritising time to improve the wording until it is conceptually tight and organisationally powerful in her lesson sequence, which she expects to have a sort of gradual unfolding of the students' analytic thinking needed for further learning of the application of lever principles.

Unlike the German case, which encouraged extensive long expressions of ideas from students, in Ms Paulin's class the rhythm of inquiry was composed using a much faster pace. Students all participated in 'instructional dialogues' as framed by

Chi (2009); strongly guided by Ms Paulin. Students actively interacted with Ms Paulin in a well-defined pattern that Ms Paulin always started with scaffolding questions to request quick and direct responses from students and students would receive confirmatory feedback and be led to more extended dialogues discussing the related concepts and principles. In the teacher enacted instructional dialogues with students, Ms Paulin kept reflecting on what was recorded by students during the course of the lesson sequence to prepare students to perform well in the subsequent activity where the inquiry question/s would be answered. In other words, Ms Paulin was able to point the students toward prior learning through referring to inquiries tackled earlier within the lever sequence and made students aware that they were building on the prior learning. Furthermore, she was also able to judge (in anticipation and through evaluation) the effectiveness of each activity as a tool for assessing the quality of students' thinking across the lesson sequence.

From the conversations we had with Ms Paulin, we can tell that she deeply believes that it is helpful and effective in the science classroom to continually ask questions to guide students to learn the correct scientific concepts. Being an expert, specialist science teacher, Ms Paulin has a good understanding of students' prior knowledge, misconceptions and language skills. For her, thoroughly thinking through intended learning outcomes of the whole teaching unit before class is essential to ensure that all students can actually answer the questions during the process and at the end of the inquiry journey be able to complete satisfying, substantial, culminating classroom activities that will show progress in knowledge as well as thinking. Therefore, we can see, in Ms Paulin's guided inquiry, how a teacher's in-lesson oral questioning can be informed, disciplined and enriched by the quality of the inquiry questions and by systematic effort to ensure that students are gaining substantive knowledge through the instructional dialogue.

Discussion

The discussion addresses two themes: first the similarities and differences across the cases; and second, the fundamental essence of inquiry-based teaching and learning.

Commonalities Across and Differences Between the Three Cases

Looking into the pedagogical practices in these three cases, they are all examples of inquiry-oriented teaching, although their forms and approaches vary a lot from each other. Basically, the key principles applied for teaching the lever unit in the three classrooms are very similar; namely the extension of the lever principle to different types of lever and their applications, the movement between class discussion and experimentation, the strong use of questioning to elicit student ideas and to move them forward (see Tables 5.1, 5.2, and 5.3). The class sequences are all organised in a dynamic, interactive way to support inquiry learning so that they all appear to have a continual shift in class organisation from whole class to small group to individual student activity as answers and ideas are generated, shared, reconfirmed, and refined (Figs. 5.4, 5.5, and 5.8). All case teachers are using questioning as a major strategy in ensuring that in-lesson transitions go beyond the routine, and students are encouraged and supported to engage in classroom dialogues and inquiry activities. Also, the transitions in all three classrooms, whether between activities, between strings of questions and answers, or between one aspect of content or another, though varied in pace, successfully help students to see the unfolding purpose of the lesson in the light of the inquiry as a whole.

However, due to these teachers holding different philosophies of science education, different goal settings for learning outcomes, and different emphases concerning the commonplaces of curriculum and pedagogy; context, content, teacher and student; there are variations in forms and approaches to inquiry teaching and learning. In the German case we can see science as a set of dialogical engagements that involve reasoning about phenomena in association with exploration through hands on activities, building and evaluating thoughts from peers, using specialised ways of talking, writing, and representing phenomena. It is believed that successful science learning involves generating a real understanding of the phenomenon in question, and is not primarily about answering specific questions correctly. From this perspective, science lessons are considered a success when students are given an opportunity to answer for themselves a question about nature by means of independent reasoning (Ramseger 2013). Therefore, the emphases of Ms Lennard and Mr Arnold's instruction are primarily on supporting and refining student communication, including students' reflective writing about their learning journey and their developing ideas, as well as group and whole class discussions. More importantly, in the classroom discourse, there is more building up from the ground, joint peer dialogues in which students' ideas are invariably respected and they are encouraged to respond to each other's ideas through a variety of devices.

In the Australian case, Mr Roberts believes it is important to engage students' attention in learning and keep them active with tasks that involve challenge and competition. In the class, there are less writing, less modelling, but more constructive activities and guided discussions. Setting the goal of engagement to develop students' investigative and problem solving skills, Mr Roberts constantly elicits students' learning interests and probes students' ideas. It appears that students are very enthusiastic in participating in inquiry activities and their ideas are acknowledged by the teacher and are shaped toward scientific conceptions in an easy discursive flow. He encourages students to clarify and elaborate on their responses, and targets particular responses, to challenge students' ideas and move their understandings forward.

Compared to the German and Australian cases, the inquiry mode in the Taiwanese classroom is much more explicitly scaffolded by the teacher and the tempo of discursive moves is much faster. It can be described as a teacher framed inquiry process. With the belief that having correct concepts and analytical thinking skills are essential for scientific reasoning and inquiry, Ms Paulin sets her priority on posing a series of guiding questions as well as using various representations to convey to students the kind of scientific thinking they must engage in and ways of using correct scientific language to describe their ideas and scientific principles. Throughout the lesson sequences which involved extensive representational re-description, from talk to writing to diagrams and graphs and embodied experience, Ms Paulin demonstrated strongly the role of inquiry questioning in contributing to students' progression in scientific knowledge and in a particular type of scientific thinking. Students in the class are all busily engaged in various explorative learning tasks designed by the teacher and are able to accomplish the final activities and intended outcomes in an efficient and effective way.

Of course, there are differences among the three cases which are worthy for us to reflect upon. For example, the age differences of students, the specificity of curriculum prescription, the length of the lesson sequence, and the levels of specificity achieved with regard to scientifically recognised principles. There is no doubt that the age differences do make differences in the emphasis of learning objectives and strategies applied. However, the specificity of curriculum prescription at the system level does impact on the length of the lesson sequences and the levels of specificity achieved in classroom teaching and learning. For the German case the curriculum of Brandenburg does specify "forces" to be taught in primary school, however standards are defined loosely and teachers are free to choose the teaching method and focus of the unit. In Australia the curriculum is framed relatively broadly such that the content to be taught in science is largely school-based or teacher-determined. In Australia the lever unit is not mandated but a suggested elaboration is to investigate a simple machine such as lever or pulley systems (ACARA 2013). Also, there is no unified teaching schedule framed by the national curriculum or unified testing at school and national levels. Therefore, there is much more flexibility and more time for students' explorations and interactive dialogues in German and Australian science classrooms. We can see there is there is an extensive exploratory lesson sequence focusing on the gondola in the German case and there is much briefer lesson sequence on the lever principle in the Australian case.

In contrast, in Taiwan the objectives of science education and the content to be taught at different school levels are basically framed by the national curriculum guidelines and there are school-based unified term examinations each year at primary level. The content coverage and time allocation for science teaching and learning are specified at system level. The implementation of inquiry teaching and learning in a science classroom is thus quite challenging. That is why we see fast-paced guided inquiry activities with the lever law and language being explicitly dealt with in Ms Paulin's class, not only in the final outcomes to be achieved in the lever lesson sequence with regard to scientifically recognised principles and applications but also in the readiness for further lessons focusing on the learning of extended, more complex principles of wheels and pulleys.

Rethinking the Pedagogical Essence for Inquiry Teaching and Learning

Many may think the forms of instruction that are inquiry-based are not to be guided; however, Herman and Gomez (2009) argue that in science education there have been sustained efforts to design learning sequences and environments that are inquiry-focused and yet provide significant guidance to learners. From the three cases presented in this Chapter we would also argue that inquiry learning occurred not only in students' peer dialogues and in teacher elicited dialogues with constructive activities, but in teacher guided instructional dialogues as well. In these three cases, the forms and approaches toward inquiry differ in ways that help us capture the important features of inquiry teaching and learning in science. These include the opportunity provided for students to hypothesize, to explain, to interpret, and to clarify ideas; the elicitation of students' interests and engagement in meaning-making and knowledge construction activities; and, guidance provided through scaffolding questions and representations to assist students to learn to practice science. The cases remind us that inquiry-based teaching and learning cannot be regarded as a single pedagogical method nor be simply practiced as student-centred teaching and learning. Rather, it is a broad orientation that can be implemented in various ways, whether through open exploration or guided investigation, involving the teacher skilfully leading students to meaningfully engage in scientific dialogues and knowledge construction.

As described earlier, the Interacademies International Working Group on Inquiry-based Science Education (2011) identified the key features of inquiry-based science teaching and learning as students developing concepts "through their own thinking using critical and logical reasoning about evidence that they have gathered" (p. 4). They also described to role of teachers as:

> … leading students to develop the skills of inquiry and the understanding of science concepts through the students' own activity and reasoning. This involves facilitating group work, argumentation, dialogue and debate, as well as providing for direct exploration of and experimentation with materials. (Interacademies Panel, IBSE Working Group 2011, p. 4)

Indeed, inquiry-based science education involves a complex set of activities for both students and teachers that are necessary to achieve the goals of the development of scientific reasoning, the ability to use ideas in solving problems, the understanding of how scientific concepts and principles arise from evidence and the dispositions of mental flexibility and respect for evidence (Interacademies Panel, IBSE Working Group, 2011). Therefore, inquiry teaching and learning in science classrooms is not just about open inquiry activities where students learn to investigate. From these, exemplar but varied cases we argue that for significant learning to occur it requires sufficient guidance from the teacher to facilitate the inquiry experiences of the students and the outcomes of students' learning of inquiry processes as well as science concepts (Wise and O'Neill 2009). The three cases illustrate different modes and levels of guidance, but in all cases the students are involved in significant reasoning through interpretation of experimentation and guided discussion.

Particularly in primary science classrooms, Kirschner (2009) argues that students are learning science and/or learning to practice science and should be assisted in their learning through an effective pedagogy and meaningful instructional design. In other words, inquiry learning has to be mediated by the teacher's teaching through thoughtfully designed instruction and assessments. Without such guidance, the cognitive developments of scientific understanding are unlikely to occur on their own (Duschl and Duncan 2009).

Since use of evidence and explanations is the basis of scientific understanding and of scientific inquiry in science classrooms, it is important to convey to students the kind of scientific thinking they must engage in during the inquiry activities (e.g., modelling, experimentation, and discussion) that will result in the development and evaluation of knowledge claims. Of course it would involve using specialised way of writing, talking, and representing phenomena, concepts and principles as we have seen in the three cases. Also, we found that questioning serves as a crucial organising and motivating tool for moving students from simple to more complex understandings through inquiry-based learning. Through each case we can discern the importance of making inquiry questions conceptually tight, and for teachers to plan their question sequences to accommodate students' learning progressions. To do this, teachers need to place inquiry within a genuine problem that demands questions of the science, and gives students the opportunity to use and develop a variety of aspects of inquiry learning in science.

Concerning the pedagogical practice of inquiry learning in science, we need to clarify the distinction between the notion of 'teaching science *by* inquiry' and the notion of 'teaching science *as* inquiry'. According to Kirschner (2009), teaching science *as* inquiry is more about "epistemology with an emphasis in the curriculum on the processes of science", but teaching science *by* inquiry is about "pedagogy that aims to use the process of science to learn science" (p. 149). Teachers differ in their beliefs about inquiry learning and their choices of instructional strategies in practice. However, if there is lack of clarity about the differences between learning and doing science in inquiry-based learning, there is a danger that the so-called discovery method, in which the teacher offers minimal scaffolding, could become the way to teach inquiry science and the importance of guidance would be ignored. When we want to promote inquiry learning in science education, we need to be very careful to avoid the impression that all science activities involve all the characteristics of inquiry or that we should expect all science teaching and learning to involve inquiry. Even the Interacademies Panel Working Group on IBSE suggests very clearly that the appropriateness of using inquiry depends on the goals of the activity and the inquiry skills used vary with the subject matter and with the age and experience of the students. Also, we need to think more about: how to motivate students and engage them in scientific thinking; how inquiry questions and instructional dialogues can be organised in a way that is sensitive to the particular social context and constructive to students' learning in science; and, overall how pedagogical practices of inquiry learning would be consistent with the objectives of the teaching unit and the ultimate goals of science education.

Conclusion

In this Chapter we have analysed three very different approaches to teaching and learning by inquiry. We have identified a key difference relating to the extent to which the teacher provides a conceptual framework within which classroom questions and discussion proceeds. In the German case for instance, Ms Lennard and Mr Arnold guided students' thinking through carefully orchestrating experimentation and exploration of students' own ideas through strategic questioning and reflecting back their ideas. Mr Roberts' practice utilised sequential dialogic and authoritative episodes as he elicited and challenged students' ideas, experimented, and shaped student's ideas in whole class discussion. Ms Paulin drove a strong conceptual agenda using targeted experimental activities and demonstrations as she introduced and reinforced key ideas, leading students use these as tools to reason through increasingly complex phenomena. We argue that despite these differences, all three teachers' practice can be characterised as inquiry according to the Interacademies (2011) definition involving critical and logical reasoning through evidence. Similarly Anderson's characterisation of inquiry as serving a reformist agenda holds. Ms Paulin sees herself as moving beyond conventional practice, and reported how she was required to justify her questioning and experimenting approach to parents who expect more standard teacher delivery. Each teacher thus grapples with different versions of inquiry, responding to the distinct histories and beliefs about teaching and learning in their countries.

In characterising the difference between the teachers we found that Chi's distinction between 'peer' and 'instructional' dialogue useful. Ms Paulin's lesson involved much more targeted dialogue, almost always between teacher and student, as the teacher probed and guided students' ideas within tight boundaries but nevertheless supporting reasoning through evidence and argumentation at each step. Ms Lennard and Mr Arnold guided the interaction through peer dialogue, encouraging talk in activity groups or whole class discussion that is less constrained. We thus argue for a defining characteristic of inquiry teaching and learning that it involves students gathering and considering evidence to actively think and reason for themselves, through dialogue and other forms of representation. From this perspective, the distinctions often attached to inquiry in the literature; that it has an inevitable focus on investigative skills, or that it is student-centred and exploratory are less central and involve separate issues of principle. These are particular types of inquiry appropriate for pursuing particular types of learning outcome.

In performing a comparative analysis of teachers in three countries we have identified particular features that relate to cultural norms and system practices in each case. Thus Ms Paulin's practice is shaped and constrained by curriculum requirements and parental expectations, and Ms Lennard's and Mr Arnold's practice reflects a strong German tradition of 'Bildung': developing students' character through collaborative communicative processes (Chap. 2). However, we are wary of the danger of essentialising each country's inquiry practices. For one thing, there will be variation within each country, and these teachers are in some respects special, and therefore cannot be taken to represent a 'norm'. We argue, however, that each can be taken to represent important principles valued in their particular culture. Our contention is that through holding these inquiry practices up to scrutiny there is something to be learnt about inquiry practices in science education per se. Realising the nature and conditions of practice in each country can raise questions that bring deeper insights not only into our own practices, but into practice as such.

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Chapter 6
Teachers from Diverse Cultural Settings Orchestrating Classroom Discourse

Russell Tytler, George Aranda, and Ines Freitag-Amtmann

Introduction

Research into classroom talk has consistently found teacher talk to dominate, with little opportunity for students to express individual ideas or contribute to the flow of lessons (Alexander 2006). The dominant discourse pattern in classrooms is that of Initiation-Response-Evaluation (IRE, sometimes known as IRF Initiation-Response-Feedback) (Edwards and Mercer 1987; Sinclair and Coulthard 1975), in which the teacher asks a question, students answer and receive an evaluative response. In this pattern students are mainly primed to offer short phrases or even one word as contributions to the classroom discussion, with little opportunity to engage in elaborated talk. Yet research has established the role of talk as central to knowledge building in science classrooms (Alexander 2006; Barnes and Todd 1977; Edwards and Mercer 1987; Lemke 1990; Mortimer and Scott 2003; Scott 1998; Sinclair and Coulthard 1975). Recent analyses (Ruiz-Primo and Furtak 2006, 2007) have extended the IRF pattern to include cycles of teacher elicitation, student response, recognizing, and using these responses to extend student thinking. Providing opportunity for students to voice and share ideas in a culture that encourages higher level conceptual exchanges is claimed to lead to more robust learning (Alexander 2006; Mercer et al. 2004).

In this Chapter we will analyse patterns of discursive moves in a sample of EQUALPRIME Grade 3–6 classrooms in Australia, Germany and Taiwan to investigate the ways in which these expert teachers orchestrate whole class discussions that move beyond simple IRE patterns. The research aims to identify discursive

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moves and patterns that are associated with teacher expertise in the three countries, and in particular to codify these moves in ways that can inform the professional learning of teachers of science.

Researching and Characterising Classroom Discourse

In this research we adopted a sociocultural perspective to analyse the means by which these expert teachers orchestrated classroom interactions to construct shared meaning (Driver et al. 1994; Vygotsky 1981). Those who analyse classroom discourse variously interpret this as a need to establish common, or jointly understood knowledge in the classroom (Edwards and Mercer 1987), as the teacher orchestrates the social construction of knowledge (Driver et al. 1994; Mortimer and Scott 2003); or as the need to establish knowledge through problem solving and the exploratory, collaborative exchange of ideas (Alexander 2006; Barnes and Todd 1977; Mercer et al. 2004).

In performing this analysis we explored discursive patterns associated with different moments in the classroom discussion, involving 'authoritative' discourse in which teachers guide students to established knowledge forms, and 'dialogic' discourse as students grapple with the new meanings opened up by science ideas (Bakhtin 1981; in Scott 1998). Authoritative discourse is directed, and intended to convey information that is considered established, and not subject to individual interpretation. Dialogic discourse is open, treading a line between ideas from others, and individual sense making. In dialogic talk utterances are treated as ideas to be actively questioned, which can be modified and extended (Scott 1998).

A number of previous researchers have developed analyses of the moves teachers make to establish meaning through talk. Edwards and Mercer (1987) suggested a hierarchy of ways teachers exercise control through classroom talk, including cued elicitation of students' ideas to mark knowledge as significant and shared; paraphrasing student contributions, offering reconstructive recaps, and direct lecturing. Mercer (2004) described a similar list of techniques including (a) eliciting knowledge from learners through direct or cued means, (b) responding to student input through confirmations, repetitions, elaborations and reformulations, and (c) describing significant aspects of shared experience, through 'we' statements, and literal and reconstructive recaps. Ruiz-Primo and Furtak (2006, 2007) identify a number of moves that teachers make to elicit student ideas (e.g., compare and contrast observations, make predictions, evaluate quality of evidence), recognise the nature of responses (paraphrases student words, revoices, or clarifies and elaborates) and use the response to move thinking forward (asking for elaboration, promoting debate and discussion, helping consensus achievement). Lemke (1990) analyses classroom discourse in terms of two components: an activity structure describing the organisational patterns of interaction, and a thematic pattern of relationships of scientific meaning. He identifies 'thematic development strategies' teachers use, such as: teacher question series consisting of linked IRF exchanges (similar to Mercer's 'cued elicitation') in which teachers might select and modify students answers, or elaborate on a student answer to place it within the theme being developed, changing its meaning; joint construction of dialogue, logical exposition, narrative (telling stories) and selectively summarising what has been said. Scott (1998) describes a range of strategies teachers use including *Shaping Ideas* (through paraphrasing or differentiating between ideas), *Selecting Ideas*, and *Marking Key Ideas* as major components, in addition to *Promoting Shared Meaning* (for instance by jointly rehearsing a student's idea in front of the class) and *Checking Student Understanding*. These categories overlap somewhat with the categories of Edwards and Mercer (1987), Mercer (2004), and Lemke (1990).

We can see that these analyses of classroom discourse have two, overlapping, components; characterising the teaching sequence structure to build conceptual meaning, and detailing the discursive moves that teachers make to shape and respond to student talk. In a previous analysis of EQUALPRIME data (Tytler and Aranda 2015) we have built on this classroom discourse research to develop a sharper, evidence based description of the discursive moves that expert teachers make, within a coherent framework of broader purposes, with the intention of using this to support teacher learning. In this Chapter we extend this analysis to include further cases, leading to a modified framework, and explore the role of cultural context in the three countries in framing these discursive moves.

We argued in the previous analysis that the effective orchestration of these moves involves a balance between the exercise of authority by the teacher to introduce and establish scientific knowledge, at the same time as allowing room for students to explore the meaning of these often new and challenging ideas, in their own language and terms. The authoritative-dialogic distinction gives expression to this duality of purpose, and our analysis further explores whether there are different patterns of discursive moves in teachers' practice in the three countries, that relate to these broader discourse types. Further we relate this to data concerning these teachers' beliefs about purposes and pedagogy, and data concerning contextual settings in the three countries.

Our research questions are:

1. How do expert teachers of science in Australia, Germany and Taiwan frame their responses to student input, in interactive classroom talk?
2. How do the patterns of discursive moves relate to the dialogic-authoritative distinction in classroom talk?
3. What cultural and contextual factors frame the patterns of discursive moves of these teachers?

Research Approach

The teachers in the EQUALPRIME project were selected as representing expert practice as judged by professional norms in each country. In each case, the local research team sought out teachers with reputations as competent teachers of primary science, through peer recommendation and/or experience of teacher educators in working with the teachers in other contexts. In each case multiple sources were consulted before the teacher was invited to participate in the study. Expertise in this study thus reflects the pedagogical affordances of each country's context of systemic practices and beliefs, rather than conforming to pre-determined practices. There were no explicit filters put on the selection that reflected particular views about classroom discursive practice.

Video records of sequences of lessons were captured for each teacher using a camera focused on the teacher; and in most cases also a camera on a selected group of students. The German team used a third camera for an overview of the whole class. Interviews were held with teachers prior to the sequence concerning their pedagogical beliefs and their intentions concerning the sequence. A later interview used stimulated recall based on the video record, to gain an understanding of how the teachers felt about what they had achieved during the lessons, and how it aligned with their philosophies and experiences about science teaching. Transcripts of selected lessons and interviews from Germany and Taiwan were translated into English.

In the analysis we have drawn on video and transcripts of typical sequences of teacher-student interactive talk in six classrooms, to describe the variety of discursive moves made by these teachers in whole class interactive discussions, in response to student inputs. The teachers were selected to represent variety in teaching setting and approach, with two classrooms selected from each country: Mr Roberts and Mr Collins from Australia, Ms Paulin and Ms Hong from Taiwan, and Ms Petersen, Ms Lennard and Mr Arnold from Germany.

For each class we identified lessons that included substantial episodes of whole-class discussion. We selected for coding coherent episodes focused on a conceptual goal, sometimes from distinct parts of the lesson, ignoring episodes of small group exploration or those in which the prime purpose was management of activity. Where it was possible, the episodes were selected for and identified as primarily dialogic, or authoritative in intent. That is, whether the discourse was primarily aimed at opening up students' ideas, or whether it was more focused on establishing agreed scientific ideas (Mortimer and Scott 2003). The coding was carried out in *Studiocode*, directly off the video, since having access to gestures, facial expressions, and tone of voice was often important for capturing the intent of the teacher's discursive moves. With the German and Taiwanese videos, we worked with English transcripts alongside the video.

Development of the Discursive Moves Framework

We used a discourse analysis methodology (Johnstone 2002) to unpack the meaning/intent of the teachers' discursive moves. We used an event sampling coding approach with the unit of analysis being a teacher utterance in response to student input. The video record was often important for making sense of what was being said, drawing on voice modulation and gesture accompanying the talk. Categories of teacher utterances were developed and refined using an iterative process between two researchers involving analysis of the nature and intent of teacher responses to student input. Each utterance was assigned to an existing code, or assigned a new code as necessary. Where there was disagreement or ambiguity, the researchers discussed this and decided whether the utterance warranted a new category, or pointed to a need for clarification or expansion of meaning within an existing category. The coding categories were refined to the point where all teacher utterances in response to student conceptual input would fit within the coding system. As part of the process, the coding categories were grouped more broadly to reflect their wider purposes in relation to exploring and shaping student understandings. The reliability of the coding framework was tested using an intra-class correlation between three raters using SPSS, resulting in a correlation (average measures) of .754, indicating a substantial level of agreement (Landis and Koch 1977). Distinctions between some of the coding categories involve refined judgment of teacher intent and the subtlety of language use operating in often complex interactive discussions, and this poses inevitable limitations on coding reliability.

In the framework (see Fig. 6.1) there are 17 distinct categories of teacher discursive moves with which the teacher directly responds to student input in interactive talk. In the coding window (see Fig. 6.1) these are separately coded from ‘new’ questions that open up lines of inquiry, and student responses that are the other part of the interaction. These response moves fall into three major categories of purpose in shaping student understanding: *Eliciting/acknowledging* student input, *Clarifying*, and *Extending* student ideas. There is a further category of *Elaborating* discursive moves that do not directly engage with student input but involve the teacher presenting the science view in an extended response that sits apart from the negotiation of meaning implicit in the discursive moves categories. The framework differs slightly from that described previously (Tytler and Aranda 2015) in the addition of Category 6 ‘review question’, which arose from the coding of sequences from two further teachers in this extended analysis. There are some clarifications in the coding descriptions which have been developed through discussion within the international team.

The Country Cases

Below are descriptions of the six cases, two from each of the three countries, with sample dialogue to illustrate the types of interactive discussions that took place and also to illustrate aspects of the framework. They are presented by country, but it is important to note that they are not being offered as representing ‘typical’ quality teaching practice, but rather that they represent important aspects of what is considered teacher expertise, in each country. Thus, a comparative analysis will need to make clear exactly what claims are being made about their representativeness in any respect. It is important to note that the detailed nature of the discourse can be expected to vary depending on the particular activity within a lesson and also within

Coding framework for teacher discursive moves	
1. New question	This involves asking a new question, which begins a new line of inquiry or discussion. This is distinct from asking a related question aimed at extending student thinking around the same conceptual idea.

Eliciting and acknowledging These are teacher moves that elicit and acknowledge student inputs and establish them as contributions that are valued in building understanding in the classroom. These moves include canvasing of further ideas, and responses to input that vary from simple recognition of student contributions, to marking out contributions for special attention. They include positive evaluations and negative evaluations (for these teachers this latter was uncommon). They are used when the teacher is encouraging and gathering responses to an initial question, to get ideas 'on the table'. *The order of the sub categories reflects increasing shaping of students' responses.*	
2. Eliciting Further Responses/Re-stating Question	The teacher further elicits ideas by canvassing other students' input, or clarifying the nature of the question. Asking the question again – 'further ideas?' 'Anyone else" Choosing another student with their hand up. 'Henry?' Asking the same question from a minimally different context. e.g. "Wood. Solid, liquid or gas? … Metal. Solid, liquid or gas?"
3. Acknowledging	Simply saying 'ok' without affirming or drawing particular attention. This could be a nod.
4. Marking	The teacher marks out the student input in some way, as worthy of further consideration, for instance by repeating the student response or a key part of it without embellishment in order to draw attention to what was said, or underlining or otherwise highlighting it on the board.
5. Affirming	Affirming interactions are those where the teacher offers a positive evaluative response to the student's response. e.g. 'exactly' 'you're right' or 'that's a good idea'. This could be a physical expression such as 'yes!' delivered with gusto, or a nod and smile. It could also be a repeating of the student answer, as with 'marking' above, but this time with a turn of voice that makes it clear this is a valued or correct response.
6. Discounting	The teacher passes judgment on the contribution, which takes it out of contention as something to move forward with. 'No, that's not relevant', 'no', 'that's interesting but can't help us in this case'. It may be purely gestural, such as a headshake.
7. Asking a Review Question	The teacher asks a question requiring an answer that should be known to the class, to reinforce a term or idea as an element of public discourse. It is distinct from a new, or an extending question, in that it goes over previously trodden ground. These are often concerned with practicing the use of new terminology, such as ' … and what do we call this point again?'

Fig. 6.1 Teacher discursive moves framework

Clarifying These are a set of response moves aimed at clarifying and sharpening the student input to achieve greater precision of meaning. These involve discursive devices that shift the language of student input to more scientific ways of talking about the phenomenon, from simply asking for students to be clearer about what they are saying, to re-voicing the input to subtly impose scientific language and perspectives. *The order of the sub categories reflects increasing introduction of scientific language*.	
8. Requesting Confirmation	Asking the student to confirm their intended meaning through repeating or slightly re-voicing the student's response, using different or more precise words, and asking for their agreement or not. 'So are you saying that … ?'
9. Requesting Clarification	Requesting a student to provide further information/interpretation concerning their response so it is clear what they meant.
10. Re-framing Question	Asking the question in a different way, with the intent to clarify what is being asked. Asking the same question but in a slightly different context, to clarify what is being asked. 'That's not quite what I meant. Let me give you an instance. If ….'
11. Re-voicing	Re-casting the language of the student response to introduce scientific language, or a related new idea. Consolidating student responses by summarising in more precise terms, imposing some order around scientific categories and conceptions. Paraphrasing to pull out main points. Introducing scientific language or ideas to re-interpret or re-shape a student's contribution to clarify /extend the implications of their input. Occasionally these moves developed further into Elaborating moves where the science view was more formally presented.

Extending These moves aim to shift students' ideas forward, by challenging students to extend or re-think their ideas or use them in another context. These are discursive moves that invite students to embellish and go beyond current ideas, to justify their claims and to reason. This may involve a sequence of further, extending questions that progressively open out students' thinking or it may involve requesting further opinion on students' input. *The order of the sub categories reflects increasing challenge to students to refine, re-think and extend their ideas.*	
12. Requesting Elaboration	Requesting a student, based on their response, to talk further about their idea with the implication of extending and elaborating rather than simply clarifying. 'That's interesting, can you talk some more about how this applies more generally' 'So if you say … can you be a bit more precise about …'
13. Canvassing Opinion	Asking for other students' opinion on the response. This move invites student-student interaction, and may involve students in claims, counter-claims and justifications. It may be simply 'who agrees with what … said?'

Fig. 6.1 (continued)

14. Asking an Extending Question	Asking a related question that introduces a new element to the discussion, that might highlight a conceptual link and ask for an extension of the idea. It is often part of a sequence of questions that take students by degrees deeper into understanding a phenomenon or a model. E.g. Mr Roberts establishes that two pieces of paper weigh the same and then asks 'if I scrunch this one up do they still weigh the same?'
15. Challenging Directly	This is an action, question or statement designed to challenge students to reconsider their response in order to extend their thinking, e.g. Mr Collins challenging the student notion of a solid being unbreakable by making a hole in a newspaper (solid). 'But if that's the case, wouldn't it imply that …?' 'Do you really think that …', 'But doesn't that contradict what we just agreed about …?'
16. Challenging to Extend Ideas	This is an explicit challenge to students to use their idea in a new context or consider the implications of their idea in a new or problematic situation. E.g. discussing liquids "Sand can change its shape to fit a container. Is it therefore a liquid?" or "ok if you have that idea can you tell me what it would imply for THIS OTHER situation"

17. **Elaborating, presenting the scientific view** A relatively extended response that relates to but moves beyond what a student said and presents and elaborates on new science ideas. It may be a summing up of the whole discussion and extending to new explanatory ideas. It may be an illustrative, explanatory story that builds on a student response. The key distinction between this and other categories is that the teacher input extends beyond the contributions of the students.

Fig. 6.1 (continued)

the sequence. There is a difference in purposes between an introductory exploration, for instance, discussion of experimental work, and pulling together ideas at the end of a lesson or sequence. No episode can be taken as typical of a teacher's practice in a detailed sense. We will therefore attempt to make clear the context for illustrative episodes, and also for the discourse pattern findings. We do not code the student responses, but in order to inform a discussion on the quality of student reasoning within the discursive passages, we have indicated where students make reasoned claims that move beyond straightforward responses to the teacher questions (*), and where they provide some form of backing for their claim (**).

The Australian Cases

Mr Roberts and Mr Collins are both specialist teachers of primary science in their schools, which is unusual in Australia but not entirely unexpected given their reputation for enthusiasm and effectiveness in teaching science. Both teachers utilise small group activity work extensively in their teaching, and begin lessons exploring student ideas, before orchestrating whole class discussion to achieve some degree of closure around science ideas by the end of the lesson.

Case 1: Mr Roberts

Mr Roberts is an experienced science specialist teacher in Melbourne. He has a philosophy of teaching children so that they enjoy the process of learning about science. Mr Roberts focuses on supporting the students to become science literate. He has a strong belief in student hands on exploration and his classroom is rich in artifacts. He carefully guides his students through introductory conversations on a new topic, acknowledging their responses with a gentle 'ok' and without evaluation. He regularly repeats their responses as a form of highlighting. As he moves the students through their topic he clarifies their understanding of the topic by reframing questions so the students get to the heart of the question being asked, and posing questions that extend their thinking. The following authoritative sequence follows student exploration of the effect of changing the shape of a piece of paper on drop time, and he engages students with the question of weight, and area, as competing explanations for why a scrunched piece of paper falls faster.

T: Did it drop because it was thicker or because it was … what was that word S1, less area	Challenging to extend ideas/requesting confirmation
S1: Yes	
T: Which one do you think?	Eliciting further response – restating question
S1: Maybe less area	
T: Maybe less area	Marking
T: Can I ask you a question, S2. Two pieces of paper, do you think they weigh the same or do you think one weighs more than the other?	New question
S2: Weighs the same	
T: Weighs the same you think. Close enough to…	Requesting confirmation
S2: [Nods]	
T: So when I scrunch it, do I change its weight?	Asking an extending question
S2: [Nods]	
S: No, no, because it's still the same piece of paper	*
T: He said yes, give me a break, what am I meant to believe?	New question
S: Well it covers less space	*
T: Oh I see, it covers less space…	Marking
S: It doesn't catch the air	*
T: It doesn't catch the air but it still weighs the same	Revoicing
T: Well you thought it weighed more. Your turn. [holds up two pieces of paper, one normal, one scrunched up]. You still think it weighs more?	Requesting elaboration/requesting confirmation

Case 2: Mr Collins

Mr Collins is an award-winning specialist science teacher in Victoria, Australia. Like Mr Roberts he has a strong science literacy focus. He has a belief in challenging his students' ideas to encourage refinement. When exploring new ideas with his students, he acknowledges their responses, but as their ideas develop he focuses on shaping their language, re-voicing their responses towards a more scientific understanding of the topic. His teaching sequence includes individual lessons on each of the states of matter, in which he first explores students' ideas, has them undertake group work to investigate variety in material properties related to the state, then brings their ideas together at the lesson's end. Below is an episode within a dialogic sequence on states of matter in which he explores students' ideas about what constitutes a 'solid', following some online reading about the definition of the solid state. Here he seizes upon a student's idea that he can challenge with an active demonstration.

T: If you're saying something's hard. What about paper? Is paper a solid?	Challenging directly
S: [Various answers]	
T: No? Ah. I'm not telling you one way or another. I want you to tell me	Eliciting further responses
S: It's not a liquid. It's not runny…	
T: It's not runny	Marking
S: You can't put your hand through it like a gas. Because you can put your hand through a gas	**
S: You can't just put your hand through a solid. You can't just put your hand through a brick, so that is a solid. [Teacher leaves room for a brief moment returning with a page of a newspaper]	
T: Hold that. Hold it. [Student holds paper as teacher puts his hand through the piece of paper]	[Not coded]
T: I can put my hand through that. Does that make it not a solid?	Challenging directly

The Taiwanese Cases

The Taiwanese cases are characterised by strongly teacher guided activities supported by extensive curriculum resources; more so than the Australian, or the German cases. Scientific ideas are introduced throughout the lessons by the teacher, with student discursive input constant, but more constrained than in the other two countries. Emphasis is placed on the achievement of high level understandings, and efficient processes for establishing science ideas before students apply them in more open contexts. Both teachers, especially Ms Paulin, in the chosen episodes, make use of 'review questions', which are not at all a feature of the teaching in the German or Australian classrooms.

Case 3: Ms Hong

Ms Hong is specialist science teacher in Taipei, Taiwan. In interview she emphasised the use of a variety of teaching strategies and contexts to achieve conceptual learning goals, and equip students for future learning. The teaching context in Taiwan includes a highly structured curriculum supported by text and multi-media resources. Ms Hong constantly monitors students' ideas, and often canvasses opinions from the class, challenges students to interpret models she introduces, and in her questioning seeks clarity and extends student thinking. The following is an episode of Ms Hong guiding her students through a model-based explanation of the phases of the Moon. Prior to this 11th lesson of 15, students had observed the moon phases and represented these, talked of lunar calendars, learnt to measure altitude and azimuth, and constructed charts. Here they are introducing models to explain moon phases. She works between two groups of students, *earthmen*, who represent the view of the Moon from the Earth, and *aliens*, who represent the view of the Moon from outside the solar system.

T: So now how does the Moon look like?	Asking an extending question
S: Left	
T: Left? [We just said right]	Challenging directly
S: Right	
T: Let's look at it this way…	
T: When you look at the Moon from the space, you should be looking at the whole ball [the Moon]	Reframing question
T: Is the ball all lit up?	
S: No	
T: Is it all dark?	Reframing question
S: NO	
T: Then which side is bright, and which side is dark?	Reframing question
S: This side is bright..	
T: How much of it is bright?	Requesting clarification
S: Half and half	
T: Right, half and half	Affirming
T: So....aliens.....have you noticed, no matter where the Moon is	Revoicing
S: It's always half dark…	
T: It's always half dark, half bright. Did you notice that?	Revoicing
S: Yes	

Case 4: Ms Paulin

Ms Paulin is an experienced teacher of science who has increasingly explored inquiry approaches in her teaching. She runs a very active classroom and likes to explore ideas with the children as they interpret models and activities. The scene takes place in the third lesson from a unit with 18 lessons. The topic is simple machines and one part of this is to learn about the lever's structure function and applications. The students are 24 sixth graders. In this lesson, the science ideas are driven strongly by the teacher as she establishes a language to analyse levers. In this episode she is challenging students to interpret bodies through lever principles, which goes well beyond the conceptual territory associated with traditional introductory lever sequences. Later in the lesson sequence students use these concepts to problem solve in unfamiliar contexts.

Our Taiwanese colleagues in analysing the unit characterised the role of the teacher in the whole class situations as authoritative. "The teacher leads the students through a sequence of questions and answers, with the aim of reaching a specific point of view. The teacher provides students with scientific terms, concepts and ideas to form a scaffolding in order to achieve teaching objectives" (Hsiung et al. 2014). In an interview the teacher Ms Paulin speaks about her beliefs on the importance of memorisation for reasoning: "Memorization is not the goal of my teaching. But being able to remember some basic concepts about lever gives students a chance to think and reason in the follow up lessons" (Chen and Ku 2014). In contrast to Germany or Australia, in Taiwanese classrooms a chorus answer from several students at the same time is common and expected.

T: When we change the application force arm, that means it will change…what?	Asking an extending question
SS: resistant force arm!	
T: See, is it changing? Ok. when the force arm and resistance force arm are changing, that will affect our effort, understand?	Affirming. Revoicing,
Ok, eight terms, can you remember that?	New question
What is it for to invent the lever by our human being?	
T: For moving stuff. OK. Please put you pencil box into the bag	Affirming
Well, please watch what I am doing. Is it similar to a seesaw?	Asking an extending question
S1: yes … similar	
T: So it is a larger one, right? I'm testing you!	Affirming
And see whether or not you've truly understood! Now I ask you a question. Where is the holding power for this beam?	Asking an extending question
SS: your shoulder	
T: I'm holding it with my shoulder, right?	Affirming
SS: yes	
T: For example, if I was just a 2-month infant, and this heavy beam is put on his shoulder, do you think the infant can hold it?	Asking an extending question
SS: Cannot	
T: If the timber beam needs to be lift up, what is the requirement for your shoulder?	Asking an extending question
S1: Must be strong	
T: It should be strong, right? Ok, it is the holding power, and what is the name for the contact point?	Affirming. Asking a review question
SS: Support point!	

T: Pivot point, and it can be simply called?	Re-voicing – restating question
SS: Pivot!	
T: Ok, come on, please tell me, where am I applying the force?	Extending question
S2: Your hand	
T: Where am I handling?	Reframing question
S2: Your hand, right hand	
T: My…?	Repeating question
SS: your right hand!	
T: My right hand is holding it and applying force on it. So what is the name for the point where my hand is holding?	[No coding]/Asking a review question
SS: application force point!	

The German Cases

In both German cases the teachers provide space for students to voice their ideas, particularly for Ms Lennard and Mr Arnold whose school has a strong child centred philosophy. In both sequences children explore through models and experiments and are gently guided to express and share and refine their thoughts. These approaches are consistent with a strong emphasis in German primary education on development of character (*Bildung*), and communication.

Case 5: Ms Lennard and Mr Arnold

The German case involves a pair of teachers who are have been trained to teach using a dialogic learning approach based on the principle that students can discover key principles by means of systematic verbalisation with the help of the teacher (Gallin 2010; Ruf and Gallin 1995). In this sequence the class is discussing a photograph of workmen in a 'gondola' on the side of a building, supported by poles with sandbags, as the beginning activity to a sequence on levers. The teachers encourage students to clarify and elaborate on their ideas, and to consider each other's ideas. They use gentle prompts and structured challenges, and re-voicing of what the students have said, to move ideas forward. The following excerpt contains teacher-student dialogue where the teachers are encouraging the students to further elaborate on their ideas. It is clear that students are accustomed to talking about each other's ideas.

T: Who needs force here? That's what came to my mind	New question
T: Do the men need force? Or what is it like?	Reframing question
T: It is a question we should maybe keep in the back of our mind, or…Yes?	Restating question
S1: Maybe it's like this: What is shown in the drawing there, carries it with the two wooden poles, with force, so-to-speak	*

T: You mean to say it has to do with the wooden poles or poles whatever material they are made of?	Requesting clarification
S1: [S nods in agreement]	
T: In which way? Can you describe more precisely what you mean?	Requesting clarification
S1: [Nods his head as sign of no]	
T: Yes?	Restating question
S2: Maybe this thing, these mountains of sand, or whatever it is supposed to be, they have to hold the whole thing, so-to-say	*
T: Aha	Affirming
And if you connect this to the word force	Re-voicing
T: What would it mean if one thought of force?	Asking an extending question
T: Here it says: I wonder if the force does not leave them?	Reframing question
T: Probably the men are meant. Whether the force does not leave the men	Requesting clarification
T: What would rather be the danger then? If one thought of the sandbags?	Asking an extending question
S3: Maybe that the poles, I think they are poles, could somehow puncture the bags and then the whole sand would pour out. And then they would fall down, the people	*
T: What could happen, if the sand trickled out of the sandbags?	Requesting elaboration
S3: Then the gondola, or what-ever it is, would fall. Because the sandbags hold the poles. And the poles help to carry the gondola. And when the sand trickles out of the sandbags, then the poles are pushed upwards. And then they would fall, the two persons sitting in there	**
T: What is the difference between S's thought and the thought in the text?	Asking an extending question
S4: In S3's thought, the force is in the sandbags. And in the text, the men hold the ropes	*
T: Do you notice the difference? Two different assumptions	Marking

In this sequence they do not introduce the gondola photograph as a lever situation but rather encourage children to bring to the table their different perspectives about force. The scene takes place on the second day of the unit. It is integrated into a 'research circle' (Marquard-Mau 2011) as the second step, collecting ideas and hypotheses to answer the research question of the day. The teachers' discursive moves can be described as interactive-dialogic (Mortimer and Scott 2003). Many student voices are established. The teacher requires clarification, elaboration and a comparison, encouraging students to think and reason by themselves. The students contribute with different claims and one student (S3) supports her claims with backing, in an extended reasoning episode. In a later sequence, the teachers work with results of a lever experiment on the board, encouraging students to generate some general principles around lever arms. Even in this authoritative sequence aimed at resolution, there were many extending moves and the discussion is speculative.

Case 6: Ms Petersen

In this episode concerning the topic of moon phases the children are sitting round a tellurium to explore what they can learn from the model. A student raises the question: “Why is the Sun made so small?” and Ms Petersen takes this question up, firstly running a discussion where children contribute their knowledge about the relative size of the Sun compared to the Earth. The discussion then shifts to the nature of models, finishing with an elaborated teacher response.

T: So why don’t they do it here? S 1?	Restating question
S1: Mhh, because one can’t make the Sun so big in this case	*
T: Why not?	Requesting elaboration
S1: Ehm, because	*
S2: it’s much too big!	*
S2: because it would be too heavy or too large	
T: Mmhhh, S3?	Acknowledging – restating question
S3: Because otherwise the whole thing would fall over, and because presumably it would smash down through the floor all the way down	*
T: That heavy? Ok! S4?	Acknowledging – restating question
S4: 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, ehm, then the Moon would be so tiny, ehm, that one could hardly see it and, ehm, then that doesn’t help	**
T: S5?	Restating question
S5: But my father also told me that the Moon is six times smaller than the Earth	
T: Well this is always the great difficulty, you will often be looking at so-called models in school that 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, for example a skeleton …,ok, then the sizes aren’t that correct, but one could see really well who flies around whom	Elaborating – presenting the scientific view

Comparing Across the Countries

In drawing comparisons across these six cases, the first thing to point out is that no tight claim is made that these individual teachers are representative, at least in a formal sense, of their country’s practice. Nevertheless it is interesting to look across the cases for features that are held in common, features that seem linked to beliefs and practices that are specific to a teacher, and features that might be taken as representing in some way the broader context and culture of a country. It is an open question as to whether there are greater commonalities within a country than across, and this question of whether we can identify major country characteristics might be answered differently depending on the particular dimension being compared. Table 6.1 provides a summary of teachers' patterns of discursive moves in each of the six classrooms, which provides an indication of difference within teachers, between teachers, and across countries. In those sequences where there were clear differences within lessons between dialogic, and authoritative episodes, we have selected and coded each of these separately in order to provide a sense of variation within a teacher's practice, and also to explore whether there are distinctive patterns of moves attaching to these different instructional purposes.

Table 6.1 lists the percentage of the number of instances for each category, for each of the teachers. The highlighted bars list the percentage of instances for the broader categories of Acknowledging/Eliciting, Clarifying and Extending. The box provides information about the duration of the clips analysed (seconds), and the percentages of this time spent in teacher conceptual talk, and student conceptual talk. 'D' denotes dialogic episodes; and 'A' denotes authoritative episodes.

From Table 6.1 it can be argued that there are dimensions of practice that all these teachers have in common, that we can associate with expert practice generally. These include (a) the use of almost the full range of discursive moves in these episodes, indicating a rich practice in each case, (b) a close monitoring of student engagement and understanding using questioning and a variety of clarification strategies, and (c) a range of discursive moves designed to move student thinking forward. In this regard we would argue that the framework works as a flexible indicator of expert teacher practice across a variety of contexts and cultures.

Similarly, there are patterns in these figures that reflect individuality in belief and in pedagogical strategies that differs within countries. Thus, Mr Collin's belief in challenge is reflected in the high level of challenge moves he makes. Mr Roberts makes many *Eliciting/Acknowledging* moves, consistent with the emphasis he puts on exploration and probing of student ideas, compared to a lesser emphasis on formal, declarative scientific knowledge. Mr Collins has in common with Ms Hong a strong emphasis on *Re-voicing* moves during the authoritative sequences, where they impose scientific language. Mr Collins does this sometimes gently but often explicitly. Ms Hong uses a range of other *Clarifying* moves including *Re-voicing*, and *Requesting Confirmation* or *Requesting Clarification*, through which she monitors students' responses to the ideas she introduces. For Ms Paulin, there was an emphasis of introducing new concepts to her students and reinforcing these with open questioning about their interpretation. These moves are clearly visible as *Acknowledging/Eliciting* moves where she uses *Asking a Review Question* in conjunction with *Affirming* moves, strongly driving the conceptual agenda. Later in the lesson she extends her student's understanding with a higher number of *Requesting Elaboration* and *Asking an Extending Question* moves as she asks students to apply these ideas to more complex everyday situations.

For the German teachers we find the greatest incidence of *Re-stating Question* codings where the teachers give students the chance to speak and respond from one student to the other without a lot of teacher talk in between. The students are given

Table 6.1 Counts of discursive moves across sequences

	Australian				Taiwanese				German			
	Mr Collins		Mr Roberts		Ms Hong		Ms Paulin		Ms Lennard and Mr Arnold		Ms Petersen	
	D	A	D	A	A	A	A	A	D	A	D	A
Acknowledging (%)	66	48	66	60	40	30	64	54	60	31	55	35
Eliciting further responses/ re-stating Question (%)	23	13	14	13	15	4	5	14	27	12	32	0
Acknowledging (%)	16	14	17	13	5	0	0	0	31	2	16	25
Marking (%)	27	4	34	28	5	9	0	14	0	3	3	0
Affirming (%)	0	8	0	8	5	17	27	19	2	12	0	10
Discounting (%)	0	8	0	0	10	0	2	0	0	0	0	0
Asking a review question (%)	0	0	0	0	0	0	30	8	0	2	5	0
Clarifying (%)	11	25	21	28	55	39	23	16	25	34	18	15
Requesting confirmation (%)	5	0	3	18	20	0	0	0	5	5	0	5
Requesting clarification (%)	5	1	3	0	10	4	2	5	15	10	11	0
Re-framing question (%)	0	4	14	5	10	17	11	0	0	8	8	10
Revoicing (%)	2	20	0	5	15	17	9	11	5	10	0	0
Extending (%)	23	27	14	13	5	30	14	24	15	37	21	50
Requesting elaboration (%)	5	17	10	8	5	0	2	8	13	10	8	10
Canvassing opinion (%)	0	0	0	0	0	0	0	0	0	2	0	5
Asking an extending question (%)	5	6	3	3	0	22	11	16	0	7	11	30
Challenging directly (%)	2	2	0	3	0	4	0	0	0	3	0	5
Challenging to extend ideas (%)	11	1	0	0	0	4	0	0	2	15	3	0
Elaborating science view	0	0	0	0	0	0	0	5	0	0	0	0
Total instances	44	83	29	40	20	23	44	37	55	59	38	20
Clip length (s)	346	934	264	314	105	90	241	220	786	674	549	124
Student talk (%)	32	21	44	37	22	41	27	38	65	33	47	39
Teacher talk (%)	38	47	36	40	85	82	82	72	30	49	46	67
Ratio of student: teacher conceptual talk time	0.84	0.45	1.22	0.93	0.26	0.50	0.33	0.53	2.17	0.67	1.02	0.58

time to express themselves and their ideas. Like Mr Collins, Ms Lennard and Mr Arnold often *Request for Elaboration*. In contrast to most of the other teachers the German teachers have a low incidence of *Marking* responses. In the German school culture, teachers are not recommended to repeat the students' response. Instead, the German teachers have the highest proportion of *Acknowledging* responses.

If we look for patterns in Table 6.1 concerning differences between countries, the first significant point of difference is the low ratio of student-to-teacher talk time for the Taiwanese episodes. The two Taiwanese teachers give elaborated discursive moves, and students' responses are quite short, such that students spend one third to half the conceptual talk time compared to teachers, whereas the ratio is more even for the Australian and German teachers. In Ms Lennard and Mr Arnold's sequence classified as dialogic, where students were being asked to link their experimental findings with other lever examples, the talk time ratio is reversed, to 2.17. These differences are consistent with the fact that the student: teacher talk time ratio is consistently lower for authoritative episodes, and the Taiwanese episodes were consistently authoritative. This is also not unexpected, that teachers in promoting scientific views strongly spend more talk time than students.

There are no clear overall country differences in the broader categories of acknowledging, clarifying and extending, but some differences in the other categories. Ms Paulin is the only teacher with a strong representation of *Asking a Review Question*, reflecting her strong guidance of ideas. The Taiwanese teachers had in common with Mr Collins a strong use of re-voicing, as they strongly guided student input towards scientific language. All teachers had a strong incidence of extending moves, but for the German and Australian teachers these often involved *Requesting Elaboration* and in Mr Collins' and Ms Lennard and Mr Arnold's cases, *Challenging to Extend Ideas*, reflecting engagement with students' elaborated contributions. For Ms Paulin and Mrs Hong the extending was often done through *Asking an Extending Question* that was carefully structured to nudge students' ideas forward in a predetermined manner. In Ms Petersen's case the high incidence of *Asking an Extending Question* was associated with her strongly structured leading of students towards being able to interpret the tellurium to understand moon phases. Therefore the pattern of use of types of extending moves reflects in these cases the degree of openness of the discourse and the degree of guidance of ideas by the teacher. Generally, the Taiwanese and the German case study teachers sit at opposite ends of this particular spectrum, with the Australian teachers occupying a middle position.

Patterns of Discursive Moves

Studiocode analysis allowed us to examine the movement between categories of each of the teachers as they conducted their lessons. Here we analyse patterns of moves to contrast Taiwanese and German episodes.

Figure 6.2 shows the screen capture of the *Studiocode* timeline for a segment of Ms Paulin's lesson, a total of 4 min. Each line shows the incidence and duration of

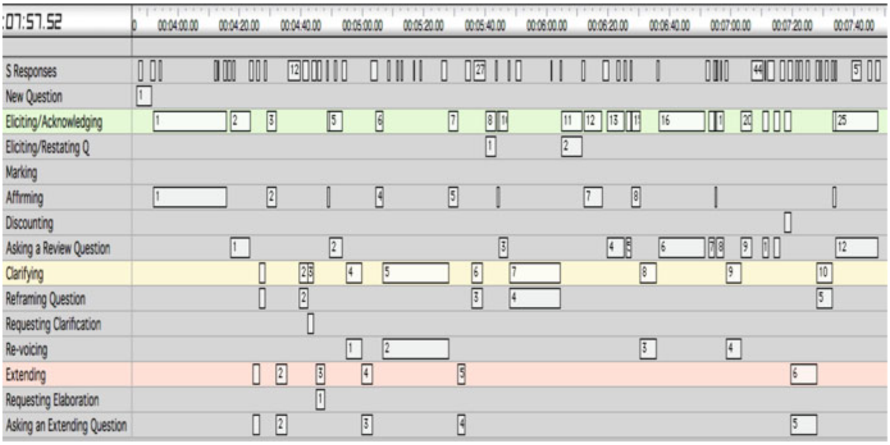

Fig. 6.2 *Studiocode* timeline for Ms Paulin's episode

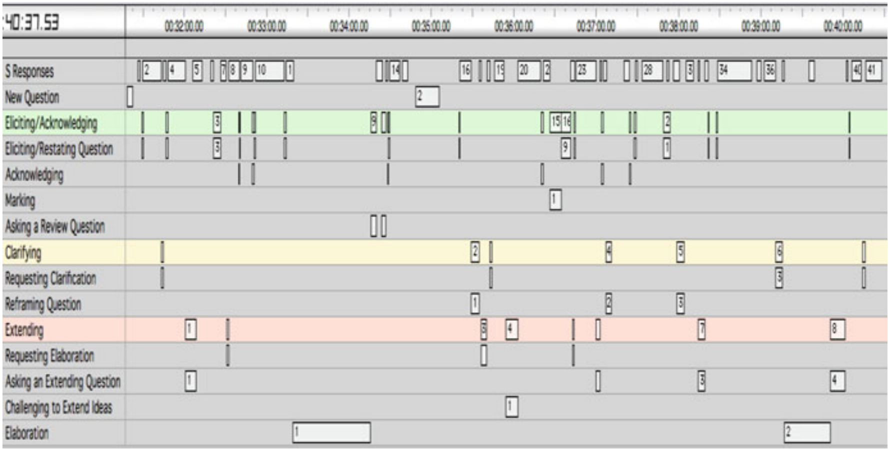

Fig. 6.3 *Studiocode* timeline for a dialogic episode of Ms Petersen's lesson

the particular discursive move, which are listed on the left of the figure, with time information across the top.

Ms Paulin was introducing the students to levers and strongly guides the discussion in the classroom, giving students the opportunity to give short, highly specific answers. We see two distinct patterns of movement here. There are sequences of progressions beginning with *New Question* or *Eliciting Further Responses/Restating Question* followed by *Asking a Review Question* often followed by *Re-voicing*. These strongly guided moves, echoing the traditional IRE pattern, can be seen in the sequences from (6:00 to 7:40). The other pattern starts with an *Extending* move such as *Asking an Extending Question*, followed by the *Clarifying* move of *Reframing Question*, followed by *Eliciting/Acknowledging* move of *Affirming*. This pattern, which asks students to generate and interpret ideas beyond the closely scripted first pattern, is evident from 4:20 to 5:40.

Figure 6.3 shows the screen capture of the *Studiocode* timeline for a segment of Ms Petersen's lesson, a total of 9 min. Each line shows the incidence and duration of the particular discursive move, which are listed on the left of the figure, with time information across the top.

In contrast to Ms Paulin's example (Fig. 6.2) is Ms Petersen's (Fig. 6.3). Ms Petersen is teaching a lesson on phases of the moon where the students are examining a model of the Earth and Moon. In the above example she uses a higher number of *Eliciting/Acknowledging* moves (32:00–40:00), such as *Eliciting/Re-stating Question* as she gets more students to talk about their ideas and share them with the class, which can be observed as longer S (Student) Responses compared to Ms Paulin's lesson. Ms Petersen allows the students to expand on their ideas, consistently *Acknowledging* them without evaluation. As the lesson progresses (35:00–40:00), she seizes on particular ideas from the students concerning the Tellurium model using *Clarifying* moves such as *Requesting Clarification* and *Reframing Question* to get the students to speak more specifically and then attempts to get the students to think further, by using *Extending* moves such as *Requesting Elaboration*, *Asking an Extending Question* or *Challenging to Extend Ideas*.

A clear contrasting feature of the two cases is the relative length of time taken in teacher moves, and student responses. In the Taiwanese case the teacher moves are long compared with short student responses, whereas in this German case, as with Ms Lennard and Mr Arnold, the teacher input is mainly short, and student responses are elaborated.

Discussion

We can identify commonalities shared by these teachers that cut across national boundaries. These include (a) the strategic use of patterns of moves to build student understanding, (b) the constant monitoring of student understanding through questioning and observation, and (c) the use of the range of moves by all teachers, from elicitation, to clarification, to extension. There are also significant differences between teachers' practices, which we have described above. A number of these differences can be associated with countries' distinctive classroom cultural features, for instance the amount of attention given to the quality of student talk, the explicitness of student reasoning expressed through talk, and the balance of who introduces ideas into the classroom discussion. These are described below.

Country Comparisons

Dialogic and Authoritative Discourse

Teacher's patterns of discourse can be expected to differ as a function of the episode chosen, depending on whether they are exploring ideas for the first time, discussing activity findings, or shaping students ideas towards a definitive conclusion. We can make sense of these different functions in part using the dialogic/authoritative discourse distinction. We found that these discourse types were distinct in the Australian cases, partially distinct in the German cases, but not distinct in the Taiwanese case. Each of the two Australian classrooms followed a distinctive pattern, beginning with a dialogic exploration of students' ideas (although in Mr Collin's case this was in response to a reading of scientific text) followed by small group activity work to explore their ideas further, and finishing with a whole class authoritative discussion in which students input was strongly shaped towards the scientific view. For the German teachers, the initial exploration was largely dialogic but students were gently guided towards a science view. In later episodes, which could be characterised as drawing together student ideas to some conclusion, the discourse again was very open and exploratory on the students' part. Therefore, it seemed to us that the dialogic/authoritative distinction was a matter of degree in these cases, rather than distinct. In the Taiwanese cases the ideas and discussion of ideas is strongly channelled by the teacher with students inputting short responses to targeted questions, sometimes 'yes' or 'no' but more often consisting of single word or short phrase responses. We argue that all these episodes are authoritative in character, but that there are differences in teacher strategies at different phases of the lesson. The Taiwanese case demonstrates how authoritative discourse can still allow room for student ideas to be voiced, albeit within much tighter conceptual framing.

Student Voice, Student Reasoning

There are significant differences between teachers concerning the ratio of student to teacher talk time in the samples of dialogue analysed, with Ms Lennard and Mr Arnold's samples of dialogue registering the greatest proportion of conceptual talk taken by students, and the least student talk time occurring in the Taiwanese samples. One can see this in the transcripts above, where both Taiwanese cases reflect a strong teacher driven practice where ideas are introduced into the public space almost exclusively by teachers, and student responses to *Extending Questions*, while requiring reasoning, are short and to the point. In the German cases, the teachers actively prompt extended student responses using *Request for Extension* or *Clarification*, or *Challenge to Extend Ideas* moves. The Australian cases fall somewhere in between, with challenges being made to student thinking that first explore, then guide student conceptual work. These differences reflect on the one hand a strong tradition in Germany of fostering communication skills and student autonomous reasoning, compared to a strong tradition in Taiwan of efficiency in supporting students to learn and apply high-level conceptual ideas and representations.

The transcripts of episodes shown above demonstrate the greater incidence of extended student reasoning for the German case compared to the other cases, with the reasoning of Taiwanese students not overt, but implied by their responses to structured sequences of extending questions. Taking an argumentation analysis of reasoning (Osborne 2010), in the student utterances marked by (*) we have examples of claims made by students and sometimes (**) claims supported by backing. The higher incidence of these in the German episodes, some incidence in the Australian episodes, and no incidents in the Taiwanese episode, broadly reflects the discourse across these units. It must be pointed out, however, that in the Taiwanese classrooms there are many examples of student reasoning, occasionally expressed in extended input, but mostly in response to tasks and problems requiring solution by students but not explicit and extended explanations.

We argue that these differences in the extent of public reasoning by students, reflects distinct cultural differences in the value given to student talk, compared to action, in the three countries. It seems that public expression of reasoning is not as highly valued in these Taiwanese classrooms as in the Australian and particularly in the German classrooms. On the other hand, one has to notice the high level of the conceptual material that the Taiwanese students are grappling with in these cases; explicit language around lever principles and their application to complex real world examples, or grappling with multiple models of the lunar cycle to explain a range of feature of moon phases. The valuing of reasoning using this abstracted scientific knowledge is associated with strong teacher direction and efficient introduction of these concepts, at the expense of extended student speculation and articulation of ideas in the public discourse. The extending discourse moves in Taiwan tend to have the purpose of challenging students to extend the scope of their ideas along a strongly structured path, whereas in the Australian and particularly the German cases these moves are often aimed at teasing out and extending ideas contributed by students.

This distinction can be viewed through the lens of Vygotsky's Zone of Proximal Development, where the language of science is offered to support students to experience new ways of thinking about the world, at a level above which they are capable of independently. The choice in the Taiwanese case is to strongly support student reasoning by structuring the language closely, whereas in the German case the language the teachers use to scaffold students' thinking is often indirect, and suggestive; offering an enticing pathway rather than a well-defined track. In the Australian teachers' practice we can see evidence of both approaches.

Cultural Determinants of the Differences

There seem to be aspects of these teachers' patterns of discursive moves that group by country, that we argue represent practices that are broadly characteristic of the prevailing pedagogical and contextual culture of each of the three countries. How can we understand these differences?

Within the research team there were frequent discussions of the setting of these classrooms, and discussions with the teachers themselves, sometimes commenting on video records of teachers from other countries. From these discussions, and from analyses of the curriculum documentation and information about the structure of schools, parental expectations, and broad values underpinning the systems, features emerge through which we can productively view these country differences.

We would point firstly to the strong curriculum framing and resource support in Taiwan, and a growing tradition of specialist teachers, that is consistent with the strong focus on disciplinary content and strong teacher direction aimed at efficient introduction and support of student learning of science ideas. The key values driving these classroom discussions include a focus on sophisticated scientific ideas, high level problem solving, and respect for conceptual traditions within science education. In German elementary school education there is a strong tradition that emphasises the autonomy of the child and the development of communication and reasoning skills. The open discussions in these German classrooms and the gentle way in which children are encouraged to speculate and reason, even in authoritative sequences, we see as consistent with this tradition. The key values that seem to be exemplified are those of communication and listening to others, and explicit and public reasoning to solve problems. In Australia group work and experiential learning are a major emphasis, but there is a strong overlay of curriculum requirements that drove the lesson structures in the cases being considered. The discursive environment in the three countries consequently differs in a number of aspects, with Taiwan and Germany being most different, and Australia falling in the middle. These aspects include the extent to which students are encouraged to articulate their thoughts, the balance of time given to student vs. teacher talk, the extent to which ideas are introduced by students, compared to the teacher, and the efficiency with which sophisticated ideas are introduced and dealt with.

The Value of the Framework

We argue that the discursive moves framework can be a powerful tool through which classroom talk can be effectively analysed, and which provides a structured rendering of classroom discourse useful to student teachers. The analysis leading to the framework breaks new ground in a number of respects, described below, which will make it valuable for teacher professional learning in identifying and promoting quality in classroom discourse.

1. The identification of a range of specific expert teacher discursive moves. These moves are more comprehensive and more specific in their descriptions than previous schemes proposed by researchers (Alexander 2006; Barnes and Todd 1977; Lemke 1990; Mercer 2004; Mortimer and Scott 2003; Scott 1998). In particular the moves identified in the clarification and the extension categories go beyond those proposed by Ruiz-Primo and Furtak in their ESRU framework (2006, 2007). The moves are generally well represented across the practice of all seven teachers in six cases, such that we can have some confidence they describe expert practice generally and are not culturally bound. They constitute a language through which teachers can analyse and reflect on their practice.
2. The identification of three broad discursive functions central to working with student's ideas to establish scientific perspectives and language. The three functions of acknowledgment, clarification and extension provide a structure through which teachers can conceptualise key approaches to supporting reasoning and understanding in whole class discussions, which go well beyond simple IRE discursive patterns. The balance of utterances across these broad functions provides an indicator of the extent to which teachers are supporting students to extend their thinking to higher levels.
3. The identification of patterns of use of these discursive moves in short sequences and more broadly across a lesson. These teachers move continually between clusters of *Eliciting/Acknowledging* moves and *Clarifying*, *Extending* moves, as they work with students' ideas to establish scientific understandings. The move towards *Clarifying* and *Extending* moves across a lesson seems to reflect these expert teachers' clarity in articulating their conceptual agenda as they work with and extend student ideas.
4. The applicability of the framework across a range of different pedagogical contexts and teacher beliefs. Each teacher used a wide variety of moves, across the spectrum of categories, even though the balance between teacher- and student-talk and idea generation was very different, depending on the prevailing culture. We argue that the framework represents the fundamental principle that students need to be supported to explore and articulate their ideas as a key element of establishing science knowledge. It is sufficiently flexible to encompass a variety of discursive strategies.

Implications

The evidence from the discursive moves analysis points to significant differences in approaches to student learning and reasoning in the three countries, on the one hand, but commonalities at a broader level in the way teachers explore and extend student ideas. The close analysis of the discourse shows how teaching and learning is a strongly culturally embedded enterprise, with teacher beliefs, system wide expectations and supports, and classroom traditions all influencing classroom discursive patterns.

However, the study shows also that these conditions are neither fixed in time, nor uniform. There is variation within countries depending on particular teacher stances. With respect to time, these teachers are in a number of cases committed to change within their systems. The Taiwanese teachers for instance are committed to moving towards more student centred, inquiry modes. The Australian teachers are advocates for a more intensive, experimental based program than is the norm in that country. Ms Lennard and Mr Arnold in particular are advocates for a child centred pedagogy that maximizes student voice and encourages extended communication and reasoning, that is consistent with but goes beyond the valuing of these attributes in the German system more generally.

One point of major significance with the framework is the way that the individual, and in particular the broad categories; are capable of capturing the range of expert practice across individuals, systems, and time. The particular operation of the categories and the balance between them is different however, and application of the framework shows up distinctions depending on the degree of teacher compared to student input of ideas. This shows up for instance in the difference between challenging students to extend their ideas, compared to extending questions which may be quite specific in their framing, and relatively closed in intent.

The validity of the framework applied to these varied cases provides confidence that we can describe expert practice in whole class discussions, in ways that transcend cultural specifics. This provides a powerful claim to its potential usefulness for teacher education across countries. We have already used the framework in preservice teacher education in Australia, and in supporting professional discussions amongst the expert teachers involved in the study in Taiwan. In both cases it is proving productive in engaging teachers in reflective analysis of practice, and we argue that the framework could be used more generally to support teacher learning. How the framework is interpreted in different countries will differ of course, due to culturally entrenched epistemological beliefs and different beliefs about purposes framing school organization, curriculum organization and resource provision. However the existence of a framework describing expert practice that can encompass these variations provides some confidence that there is a core of practice that attaches to quality teaching and learning, that teachers from any country can subscribe to and interpret from their own standpoint.

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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.

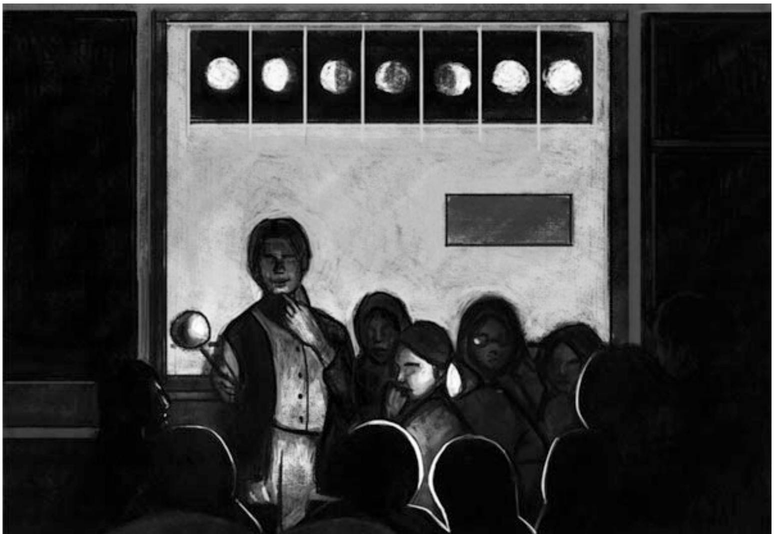

Fig. 7.1 Students gather around to see the lit moon from different angles

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?

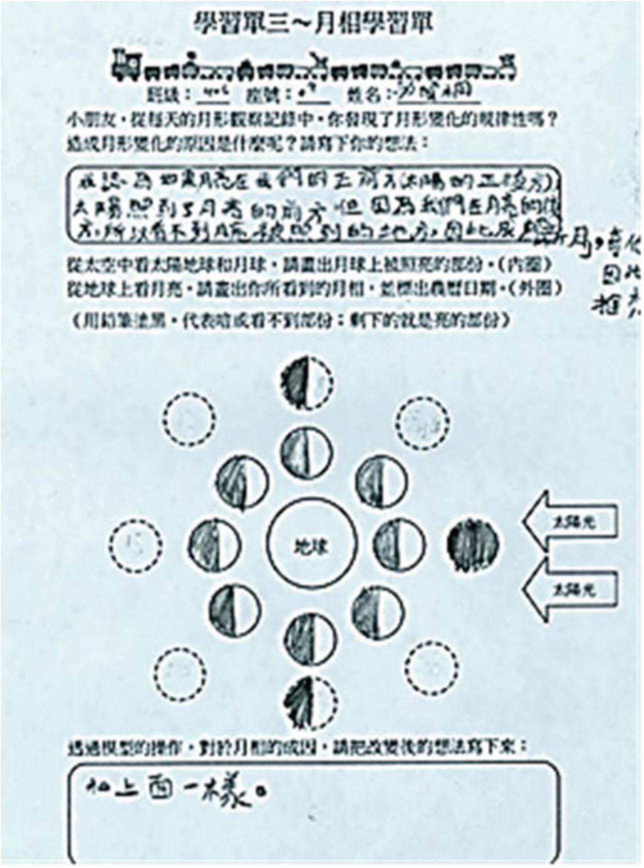

Fig. 7.2 The worksheet, partially filled in, showing the space and earth views of the moon phases simultaneously

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.

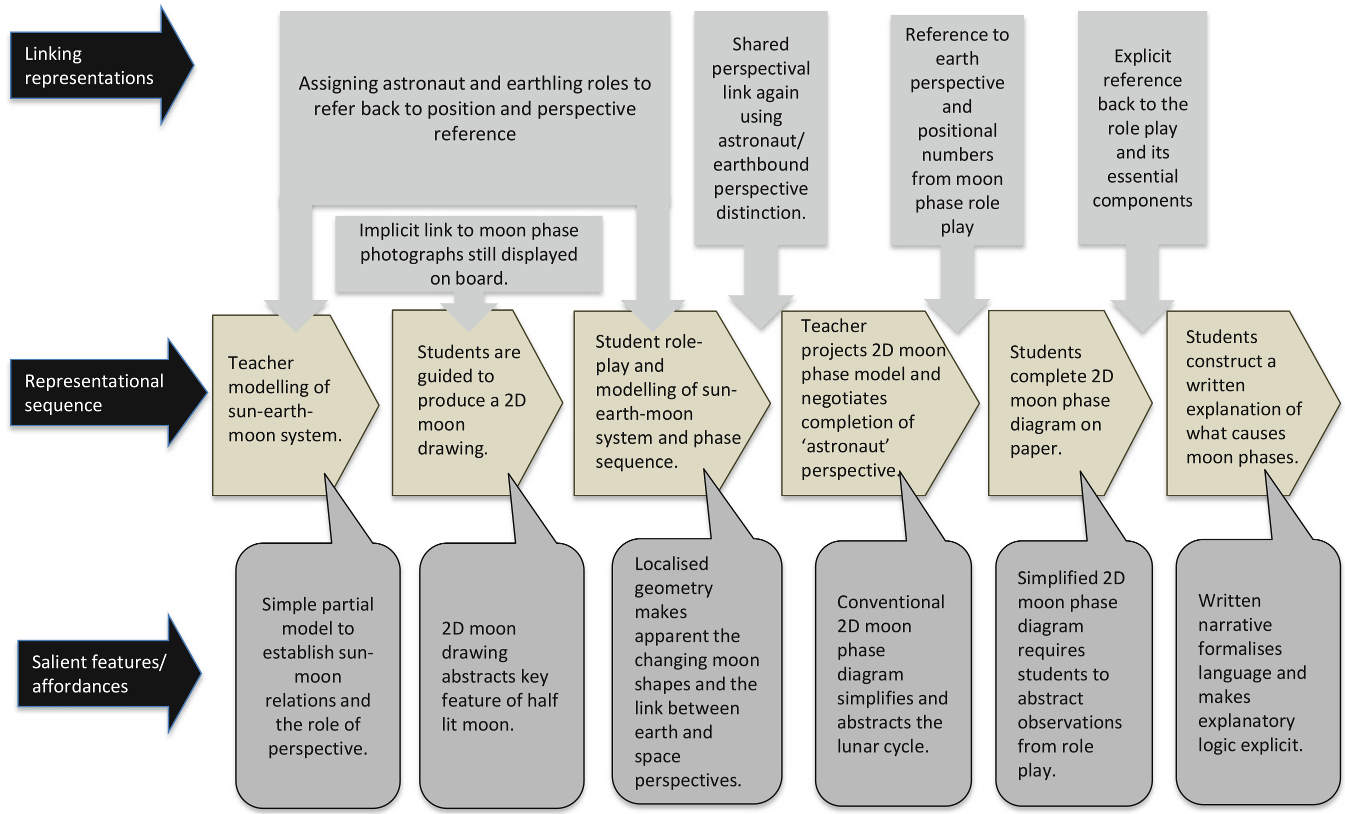

Fig. 7.3 The sequence of representations, their salient features, and linking moves used by Ms Hong

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

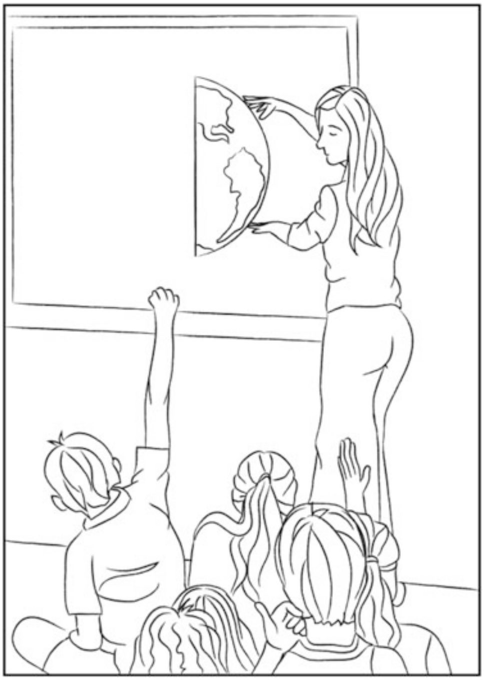

Fig. 7.5 Animation of the Earth spinning: "The Sun would be here providing all of the light on this side of the globe"

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):

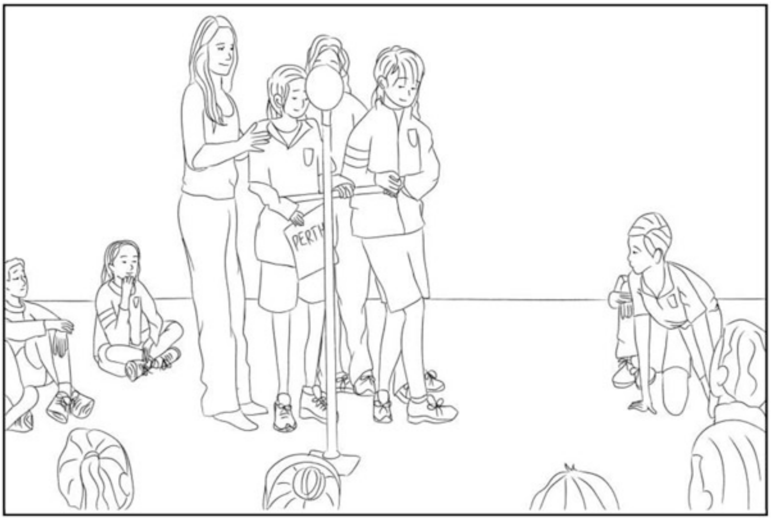

Fig. 7.6 Role-play of spinning earth – “Let’s spin so that Perth is in daytime”

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

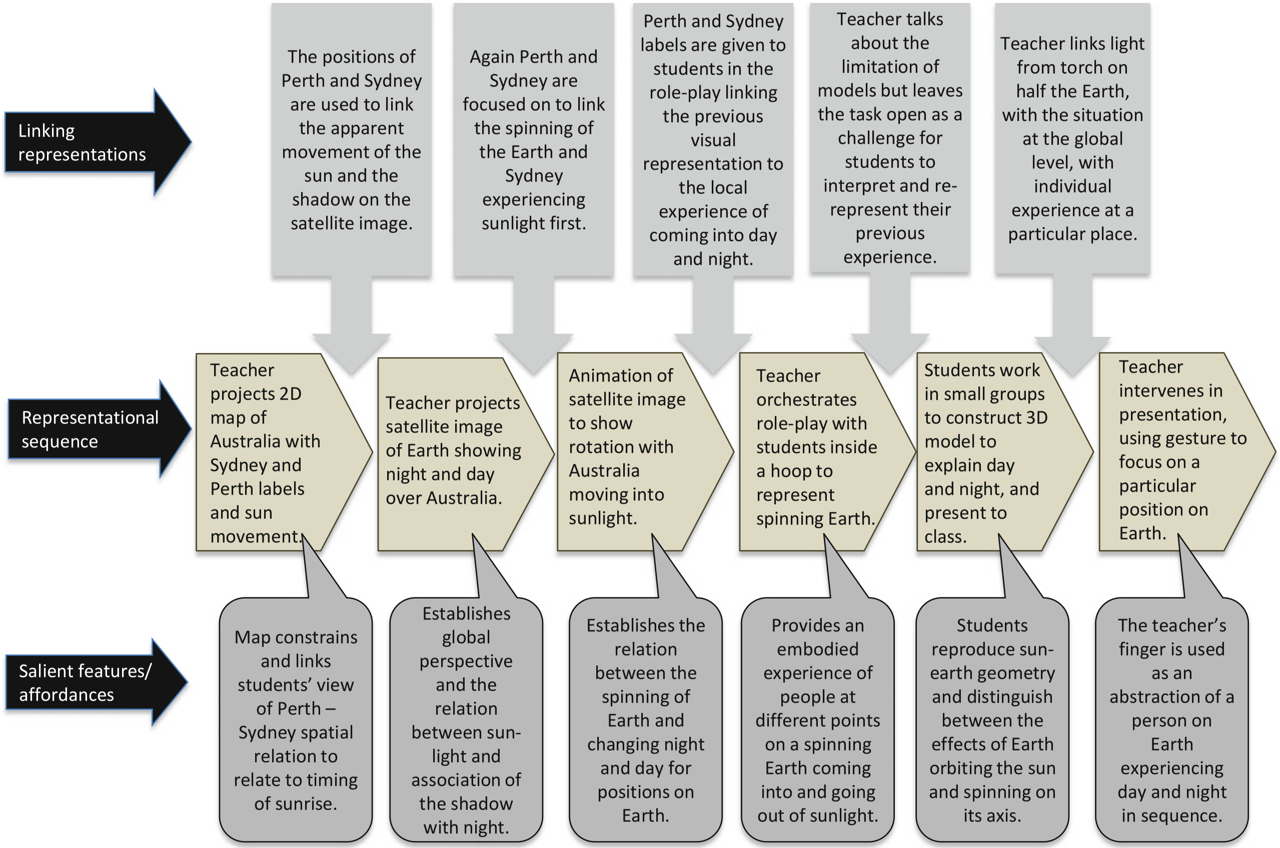

Fig. 7.8 The sequence of representations, their salient features, and linking moves used by Ms Grace

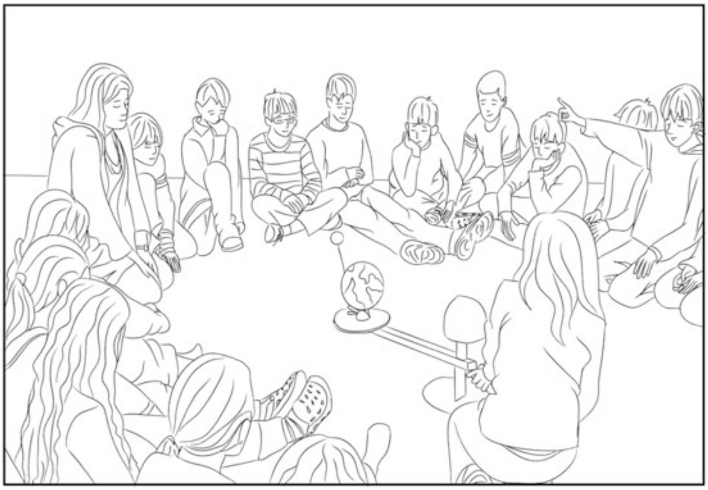

Fig. 7.9 The children sit in a circle to discuss the Tellurium model and its implications

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.

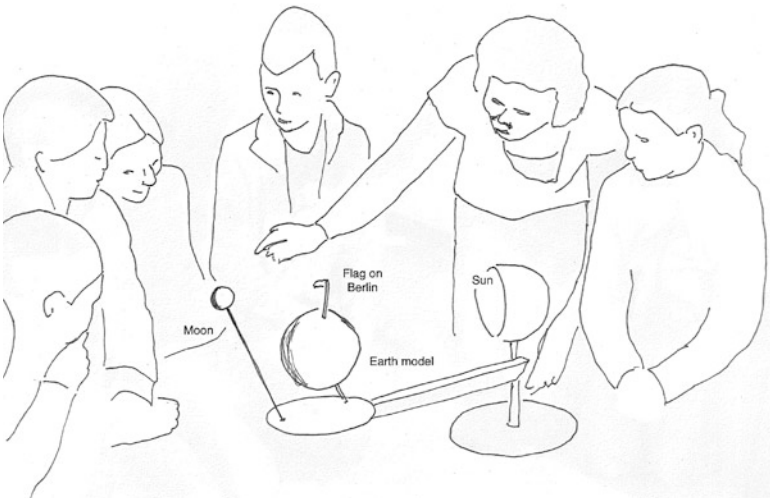

Fig. 7.11 Ms Petersen focusing attention of the lighting situation for a full moon

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

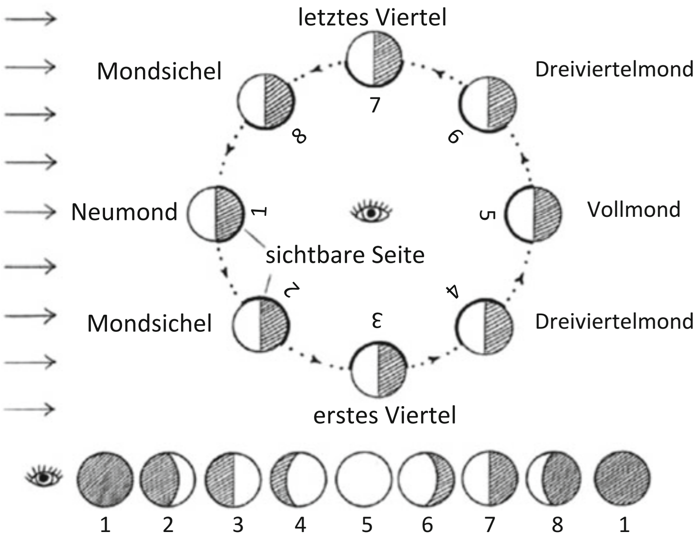

Fig. 7.12 2D representation linking phases (new moon, crescent, first quarter, three quarter moon etc.) as seen from earth with points in the Moon's orbit (Reproduced from "Sichtbare Seite": "Visible side" (http://www.sonnentaler.net/aktivitaeten/astronomie/himmel-erde/mondfinsternis/, © www.sonnentaler.net,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

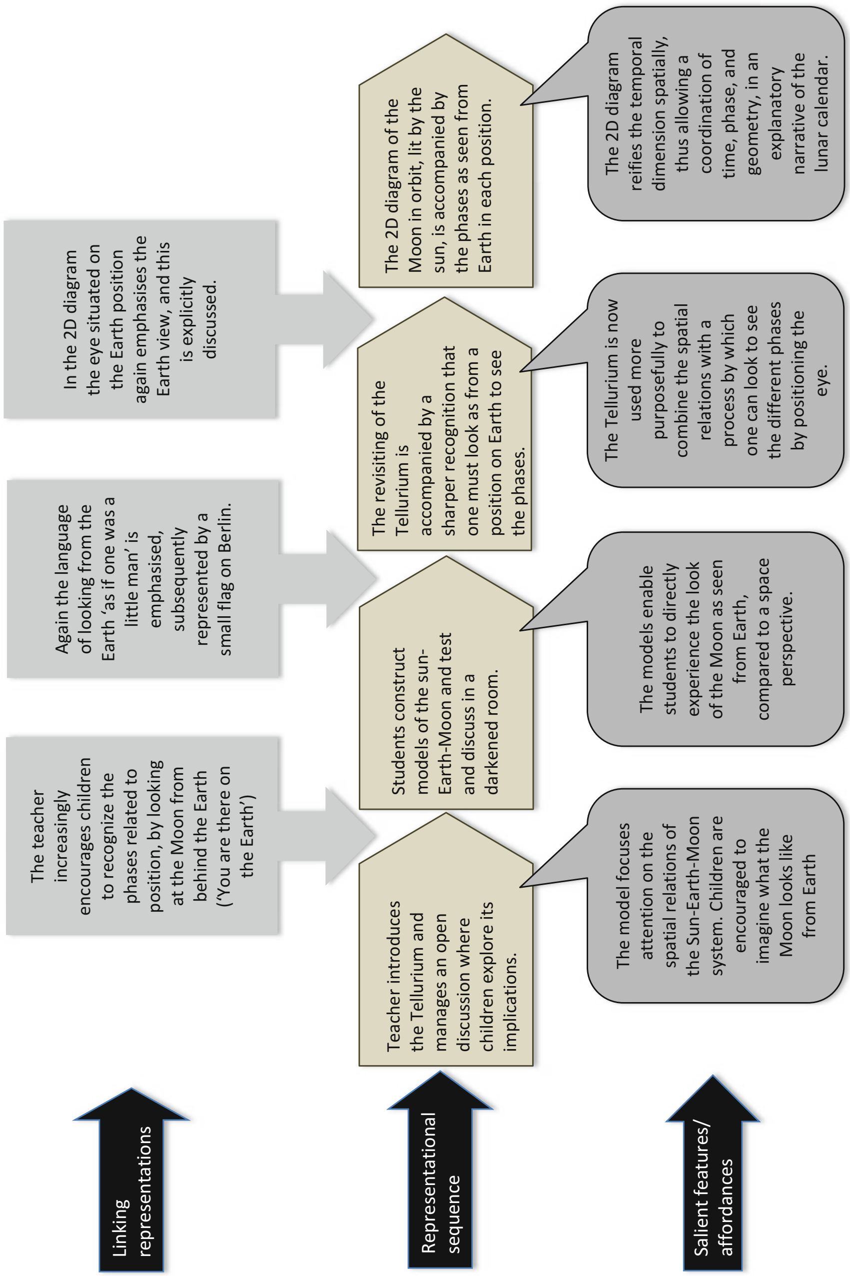

Fig. 7.13 Ms Petersen's sequence of modelling activities

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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Chapter 8
Embodied Strategies in the Teaching and Learning of Science

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Introduction

Teachers use all available resources including the different forms of representation to engage, elicit and scaffold the development of student understanding. Effective teachers orchestrate the learning process (Hackling et al. 2013) by drawing students attention to certain ideas, connecting them to students' prior experience, and developing relationships between concepts and student experiences through representations that are relevant and meaningful to enhance scientific understanding (Carolan et al. 2008; Prain and Waldrip 2006).

Although there has been a deep inquiry into the use of representations, their role in student learning and the pedagogical affordances such representations provide to engage and foster science learning (e.g., Carolan et al. 2008), the research on the topic has remained firmly focussed on those forms of representation that can be 'fixed' and documented in tangibly reproducible data forms such as speech, graphs, and written text. Significantly, these forms of representation are also those that have been canonised within the field of science. Representations that rely on the body including gestures, object manipulation or those that involve the whole body (full-bodied representation) have not had similar research attention. This Chapter aims to respond to this gap in the literature by focusing on theoretical contributions from social constructivist, social semiotic and complexity theoretic body-based approaches to argumentatively establish the need for integrating body-based representational forms within multimodal approaches to science teaching and to

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understanding learning. Three primary science classrooms in Western Australia and Germany, were selected as illustrative cases due to the underpinned student centred approach and rich teaching and learning episodes to demonstrate how body-based representations were used by teachers. This Chapter makes the case for researchers and teachers to be attentive to the use of gesture, full-bodied representation and object manipulation as examples of embodied forms of representation and communication, and their impact on student learning.

Embodiment

Body-based researchers subscribe to the idea that "human cognition is deeply rooted in the body's interaction with its physical environment" (Lindgren and Johnson-Glenberg 2013, p. 446). They foreground the physical body or parts of it as a distinct and bounded site for sensing, an active constituent part of the meaning making process and lastly as a representational tool.

A more recent focus on the use of the body as a conceptual resource (Lakoff and Johnson 1999) is also evident within the field of science education (Roth 2000; Sakr et al. 2014). This focus highlights the affordances that body-based strategies may provide for teaching and learning. However, there is a lack of clarity or consensus in the way the term 'embodiment' is used within the literature (Kiverstein 2012). Nevertheless, most approaches subscribe to the notion that the meanings we are able to make with and about the world are dependent on the "kinds of experiences that come from having a body with various [and specific] sensorimotor capacities" (Varela et al. 1991, p. 173). Furthermore, learning is seen as "depend[ing] crucially on our bodies, especially our sensorimotor apparatus, which enables us to *perceive, move, and manipulate*" (Lakoff and Johnson 1999, p. 17, our emphasis).

In this Chapter, we use the term embodiment to encompass three different aspects of body-based meaning making:

1. the physical body and its sensorimotor capabilities;
2. the use of objects to extend the sensorimotor capabilities of the body for a particular purposes; and,
3. the embedding of the body in a deeply situated sense-act-process loop to make and represent meaning.

While such aspects could be manifest in many body-based representational forms, for the purposes of this paper, we limit ourselves to some embodied elements that can be practically used to transform science teaching; gestures, full-bodied representation, and object manipulation. Although finer distinctions can be made in terms of distinguishing facial expression and changes in tone of voice, we have kept the focus on elements of body-based meaning making strategies that can be reproduced or identified for practical use within classrooms such as pointing (gesture), role-play to demonstrate the pushing of a shopping trolley (full-bodied representation) or turning a ball to show how light falls only on the side facing a light source (object manipulation).

It is worth mentioning that although some use of embodied representations can be involuntary on the part of the teacher, we focussed on the intentional and planned use of bodily gestures identified through pre and post lesson discussions. In addition, we also included those representations that arose involuntarily and were recognised for their value and then used explicitly in ensuing discussions and lessons.

Many teachers use embodied strategies such as gestures that are deictic (pointing), iconic (visually similar), metaphoric (conceptually related), or beats (pacing) (McNeill 1992) to complement their verbal communication. Others engage students in full-bodied representational approaches such as role-plays to scaffold student learning.

In addition, teachers often capitalise on the notions of the extended body to enhance teaching and learning through object manipulation. However, if teachers are to maximise the pedagogical potential that these strategies offer for student learning within multimodal learning events, it is apparent that they must focus on the impact of embodiment on "indirect effects on communication with the learner, and directly through its effects on the learner's cognition" (Goldin-Meadow 2010, p. 1).

Multimodality

Our discussion of embodiment is also situated within the research paradigm of scientific representation that has significantly expanded and evolved recently within the domain of science education (e.g., Prain and Tytler 2013). Research on representation has addressed the semiotic potential available in the different representational modes (Ainsworth 2006; Kress and van Leeuwin 2006), the inherent pedagogical challenges of dealing with multiple modes of representation (Waldrip et al. 2010; Hackling et al. 2013), as well as how students exploit such representations in meaning making (Hubber et al. 2010; Tytler and Prain 2010; Prain and Waldrip 2006).

Significantly, initial research on the representational competence (diSessa 2004) of students focussed on representational forms of science canonically used within the discipline, such as discourse, diagrams, tables and graphs. More recently, attention to how students engage with scientific representations has shifted to multimodality: the "full range of communicational forms" that are used by students to construct and communicate scientific meaning (Jewitt 2009, p. 14), particularly in complex combinations and ensembles of modes (Kress 2010). Such multimodal use foregrounds the new meaning potential (Björkvall and Karlsson 2011) that is available when these modes are used together, and enhances the ease and flexibility afforded to students in communicating their understanding of scientific ideas (Prain and Waldrip 2006). Research has also focussed on students' ability to move fluidly between representational forms (Kress 2010; Larson and Segal 1995), the increased conceptual engagement that arises from engaging with different forms of represen-

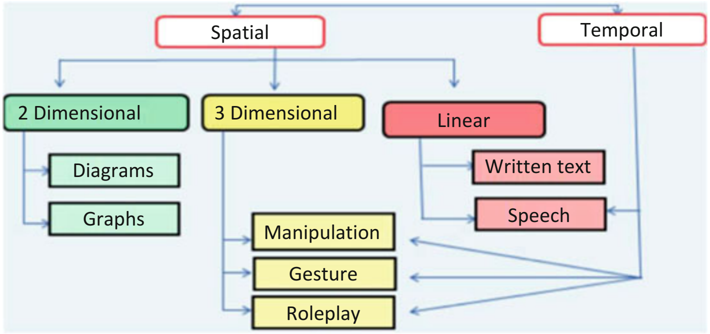


Fig. 8.1 Material affordances offered by typical representational forms used in classrooms

tation and re-representation, literacy of the languages of science (Carolan et al. 2008) and reasoning (see Tytler et al. 2013 and Chap. 9).

Representational meaning making involves the simultaneous perception of, ‘thinking with’ and ‘thinking through’ representation (Ainsworth 2006; Waldrip and Prain 2012) leading to new understandings and possibilities. The unique affordances (Gibson 1954) each representational form provides for meaning making informs how the different modes can work together in a complementary fashion (Kress et al. 2001). They elaborate, extend and enhance the potential for teachers and students to make meaning (Jewitt 2009).

The two processes of ‘thinking with’ and ‘thinking through’ multimodal representations require a deep understanding of the contribution of embodiment within scientific meaning making. If we consider the representational forms used typically in science classrooms, we see that the different affordances they offer (Fig. 8.1) will allow different forms of meaning to emerge from multimodal ensembles within classroom communication. For example, a teacher gesturing and spinning a finger around while explaining day and night using speech to describe the number of hours required for the rotation of the Earth will provide a sense of pace, a numerical number of hours, the direction, angle of the axis of rotation as well as other information that may not have been communicated with speech. Therefore, a deep examination of how the body (physical, embedded and extended) acts as a representational resource and how embodiment works in ensemble with other representations is needed to underscore the potential it provides to enhance quality teaching and its impact on student learning.

The Relevance of Embodiment to Science Education

The contribution of embodied approaches to science teaching and learning is found within practical work in science teaching, and where gestures (Roth 2000; Sakr et al. 2014) and whole-body representations such as role-plays utilise the body in generating, supporting and communicating understanding. The emphasis within the literature on the role of activity and practical work (Woolnough 1990) in facilitating experiential (Dewey 1938; Kolb 1984) and deep conceptual understanding (Osborne and Freyberg 1985) is longstanding. However, most body-based experiences, with the exception of gesture (Kontra et al. 2012) have not been explored in depth for their representational impact on student learning.

Gesture

Gestures are identified mainly as hand actions, and are typically classified based on their functions (Goldin Meadow 2011). Although some classify all non-verbal actions that are carried out for communication purposes as gesture, we limit gestures to hand based communication to distinguish the different affordances available through the specific use of hand gestures from other embodied representations (Sakr et al. 2014). From a multimodal perspective, gestures are more than just hand movements that accompany our speech or other forms of communication; they also deeply impact what students learn and how they learn (Goldin-Meadow 2011). Student learning occurs through their own gesturing as well as through the gestures of other students and teachers (Goldin-Meadow. 2011).

Gestures offer visually rich potential for scientific meaning through deictic (pointing), iconic (perceptually similar) or symbolic (semantically similar) functions (Roth 2000). Sakr et al. 2014 argue the need to reclassify the representational potential of gestures to emphasise the manipulative, epistemic, deictic and re-enactment functions that are served. Although other functional taxonomies exist (Cook and Goldin-Meadow 2006; Goodwin 2003), the taxonomies developed by Roth (2000) and Sakr et al. (2014) inform the following discussion due to their comprehensive and functional focus on science learning. Roth (2000) identifies gesture as stepping-stones for students in their development of disciplinary language. He argues that students work their way through using pointing gestures to identify an object, developing the ability to utilise visually similar gestures in iconic representational form prior to acquiring the facility to use metaphoric gesture and before they are able to verbalise their understanding. Although such description appears to suggest that students become independent of the need for gestures once they develop command of proper scientific vocabulary and language, gestures are of course still at play and influence understanding even for those who are literate and fluent. For example, gesture can be used as iconic actions such as twirling a fist around (Hegarty et al. 2005; Schwartz and Black 1996) even by those who have command of the vocabulary to illustrate the pace and the spatial elements of the orbit of the Earth around the Sun. The spontaneity of such gestures often arise when students are required to respond in the moment (Crowder 1996).

Gestural action also helps students develop and communicate new ideas and strategies in problem-solving situations (Broaders et al. 2007). The immediate heuristic response required in such situations benefits from the multimodal communication to draw on the not-yet verbalised concepts, and those that require three-dimensional and temporal representation to inform the communication within the problem-solving event. Although these representations are not fixed (Kress 2010) they can have long-lasting impact on students' ability to retain knowledge (Goldin-Meadow 2011).

From a representational perspective, student learning is informed by gestures as a result of the "actions that are representational and exert their force in conversation" (Ping et al. 2014, p. 203). Gestures not only make spatial content of communicated ideas accessible; they also can help learners engage with the presented ideas. Significantly, gestures have noteworthy effect on the immediate comprehension of listeners when they communicate the same message as speech, but are more memorable longer term when they present additional information to that which is presented verbally (Hostetter 2011).

Attention has recently turned to scripting teacher gestures for maximum effect in teaching and learning (Alibali et al. 2014; Majlesi 2015). Although much of this work has been within the Mathematics and Second Language domains, similar work in primary science teaching has addressed how such scripting helps students make sense of space and time (Padalkar and Ramadas 2011). The evidence that children are impacted equally by both spontaneous and scripted gestures of others, and benefit from them in similar ways (Hostetter 2011) invites teachers to decisively plan and design their use of gesture within their multimodal communication to ensure that learning is scaffolded in a targeted way.

Role-Play

Role-plays extend the scope of embodied representation within science teaching (Aubusson et al. 1997). Role-plays typically use two analogically impactful approaches; taking on the roles of other people or animals, or personifying objects and entities to stimulate an immersed understanding of the phenomena being explored. We use the term role-plays loosely, to describe teaching approaches including dramatic ones (Braund 2015) that exploit the representational potential available when students are provided opportunity to approach a scientific phenomenon, from another perspective (Dawson 1994) that draws on prior experience.

Goldman-Segall and Goldman (2014) explain that "various points of viewing, by continuously examining how others see what we see and comparing this to how we see what we see" (p. 216) is the basis of complex knowledge. Providing opportunity for students to move using their whole bodies, as well as to utilise a visual-spatial perspective from a new vantage point helps them triangulate spatial content (Plummer et al. 2011). Actively taking on the role of an object to understand the target phenomenon helps students extrapolate their understandings from the embodied spatial and temporal perspectives of their prior experiences of moving around.

Niebert et al. (2012) argue that embodied experiences are required for analogic meaning making, when the learning demand is high. Students may appeal to bodily experiences in place of analogical source material teachers provide to help them to make sense of new information (Gentner 1989). Students' self-generated analogical meaning can be compelling due to the spatial and temporal coherence of lived experiences which can be utilised to shape conceptual understandings (Lakoff and Johnson 1999). Full-bodied representations enable students to use the rich conceptual resources such as perspective and spatial awareness, available in embodied form for making meaning.

Explicit prompting of full-bodied student representations or role-plays can also be particularly useful to help teachers comprehend students' intuitive understandings. Encouraging students to use such embodied representations allows teachers to formatively assess how students' understanding compares to scientific knowledge.

Object Manipulation

The term embodiment is also used as a means of addressing the tacit as well as the more utilitarian manipulation of objects in practically 'doing science' (Woolnough 1990). Students and teachers often use equipment and physical objects in the science classroom to develop a more hands-on, activity-based approach to understanding science (Millar and Abrahams 2009). However, the representational impact of such manipulation is often overlooked in its relationship to the body (Prain and Tytler 2012).

Practical and activity-based work has been found to enhance students' engagement in primary science contexts (Millar and Abrahams 2009). However, in a broad study of the effectiveness of practical work at the primary school level in England, although students could describe what had happened, no changes were documented in their scientific ideas (Abrahams and Reiss 2012). This means that, for the most part, primary aged students do not explicitly recognise the representational aspects of their manipulation of objects. The doing of the science was seen as a means to an end. As a result, the manipulation does not always anchor students' developing scientific understandings to the manipulating, which can offer rich spatial and temporal representational resources (Hutchins 2005; Chandrasekharan and Nersessian 2011).

According to the extended body view, "[t]he human mind … emerges as the productive interface of brain, body, and social and material world" (Clark 2008, pp. 218–219). The task of scientific sense-making is distributed across members of groups and the objects in the moment as they use these objects to explore ideas individually or in groups (Hutchins and Saeko 2011; Osbeck and Nersessian 2014). The upshot of this kind of extended thinking is representationally significant.

Extended, embodied, representation allows the perceptual and relational aspects of the body-tool-use complex in practical work to become visible and accrue meaning as part of a sense-act processing approach (Clark 1997; Pfeifer and Scheier 1999).

Model-based reasoning also attends to the extended bodied view through its focus on how physical models extend the ability to make meaning (Duit 1991; Nersessian 2006). Although much of the model-based reasoning research focussed on pedagogical models (Nersessian 2009; Vijapurkar et al. 2014) that highlight the spatial value students construct from engaging with these models, an extended embodied view demands the focus to be on the momentary impacts of object manipulation, perception and representation (Ingham and Gilbert 1991) and identifies the responsive aspect of sense-making.

An analysis of teachers' timely use of modal representations to exploit the affordances of each mode and in ways that can maximise learning help establish the quality of the teaching as well as the pedagogical significances that underlie the use of such embodied approaches. By attending to the sequences of activities that the teachers used, the functional contributions of the body become foregrounded. The way in which these opportunities help students continue deep engagement and elaboration of the expressed scientific ideas through the simultaneous use of multiple representational forms including embodied forms, allows a qualitative map of student understanding to become explicit.

In light of the above, this Chapter illustrates how teachers use embodied representations in the form of gestures, role-plays and object manipulation, and in concert with other modes of representation to support student meaning making and quality learning. We propose that to better understand quality science teaching, further exploration of how body-based strategies are effectively used within primary science contexts is needed. The EQUALPRIME study offers a unique opportunity; one that can compare the use of embodied teaching and learning across different cultural contexts. We focus on three different case studies within the EQUALPRIME project that explored quality science teaching in Australia and Germany to document the body-based strategies used by the teachers to support student understanding of concepts in Grade 4–6 science classrooms.

Research Questions

To help elucidate the role of body-based teaching and learning we asked the following research questions:

1. What embodied forms of representation do teachers use to scaffold students' scientific reasoning and learning in primary classrooms?
2. How do these representations help students learn?
3. What differences do we observe across the cases set in different cultural contexts in how embodiment is used in science teaching?

Theoretical Framing

To answer the above research questions we employed a number of theoretical frames to attend to the multiple facets of the problem. Similar to the earlier chapters we adopted an emergent and dynamic ecologically complexivist embodied frame (Maturana and Varela 1987) interpreted through overarching social constructivist (Vygotsky 1978), sociocultural and social semiotic (Kress 2010) frames that focussed on multimodal learning to reveal the dynamic nature of body-based representation. The social constructivist frame attended to the way the body (physical, extended and embedded) was constructed as a meaningful representation through culturally contingent, socially negotiated processes (Vygotsky 1978) and the sociocultural frame was employed to nuance and produce justifiable conclusions through explicitly addressing the interlocking scientific, school and larger cultures of the local society that shape how students and teachers may produce meanings in context.

We also drew on a social semiotic view (Kress 2010) to foreground the socially situated signifying processes that the teachers and students engage with to ascribe representational significance to the physical, extended and embedded bodily acts in which they engage. The ecological complexity theoretic perspective (Maturana and Varela 1987) to embodied cognition (Lakoff and Johnson 1999) considered meaning making to be complex and tacit, dynamic and body-based, as well as distributed, allowed the examination of the different representational potentials that emerged in classroom learning. This involved gesture, role-play and the manipulation of objects alongside other modes of representation and communication. Detailed discussion of the main theoretical (social constructivist and social semiotic) frames are delineated in the introductory chapter of the book and have not been elaborated here. The embodied and complexity frames are intended to be demonstrated in the analysis of the vignettes by presenting how embodied representations work in meaning making, both bounded representations in the form of gestures and full-bodied representations, as well as the emergent and distributed coherences that arise in the manipulation of objects (Maturana and Varela 1987).

Method

In this study, each lesson in a sequence of lessons within a unit of study was video recorded, and lesson plans and teaching materials were collected following the shared repertoire of the EQUALPRIME study as described in Chap. 1. A short informal 3–4 min interview was conducted with the teacher prior to each lesson to identify the pedagogical intent of each lesson. At the end of the lesson, the teacher spent a few minutes with the researchers, recapping and reviewing the lesson. All teacher interviews were audio recorded.

After each lesson student learning artefacts were collected and the focus group of four to six students; who were tracked throughout each of the case studies, interacted with the researchers to debrief and discuss their scientific learning. Interviews were conducted and video recorded with the focus group students at least once throughout the lesson sequence, some of which were video stimulated. The interviews were constructed by the researchers in ways that enabled students to utilise any material resources that they needed from within the classroom and any form of representation to communicate their understanding so that their responses could be documented multimodally. Extensive pre-unit interviews with the teachers and video-stimulated post-unit interviews with the teacher(s) and the focus group were also conducted. Student artefacts, lesson plans and teaching materials were also collated for analysis.

As the focus was on the embodied elements that were expressed as the lessons unfolded, video was the central data source that informed this study. However, interview data, artefacts and other data sources were used to represent any significant elements, and triangulate findings when appropriate. The longer term impact of such embodied practices requires further research.

All recordings were viewed and reviewed in its entirety to get a deep familiarity with the content of the video. The video was played back within video analysis software (Studiocode or Videograph) repeatedly with and without sound to pay particular attention to when body-based strategies were utilised.

A micro-ethnographic, layered approach to data reduction was employed in that only the clips of interest that indicated body-based representational content from the teacher or student were initially 'tagged'. These tagged clips were then re-analysed to visually identify modal density regions (Norris 2004) when embodied modes overlapped (Hackling et al. 2013) the simultaneous use of other representational forms (see Fig. 8.2). This process allowed the data to be funnelled to extract the vignettes where embodied representations were used multimodally by the teacher(s) and students.

The video instances that demonstrated the use of embodied representational forms were then interrogated further to classify and code them deductively as gesture, object manipulation or full-body representation (role-play) as identified within the literature. To provide a more responsive generative approach consistent with the micro-ethnographic approach, these codes were refined into subcodes constructed in a bottom-up fashion to further differentiate the codes (see Fig. 8.3). As the codebook evolved, and as each vignette was analysed, the codes themselves and their emerging hierarchy and structure were checked for consistency against the data.

The software was then used to attach descriptive memos that provided commentary about the embodied representations to each of the coded video instances within the vignette. These descriptive memos were integrated within a multimodal transcript (Hackling et al. 2013) providing information about all the modalities, to inform how the codes were contextually situated within the events that occurred.

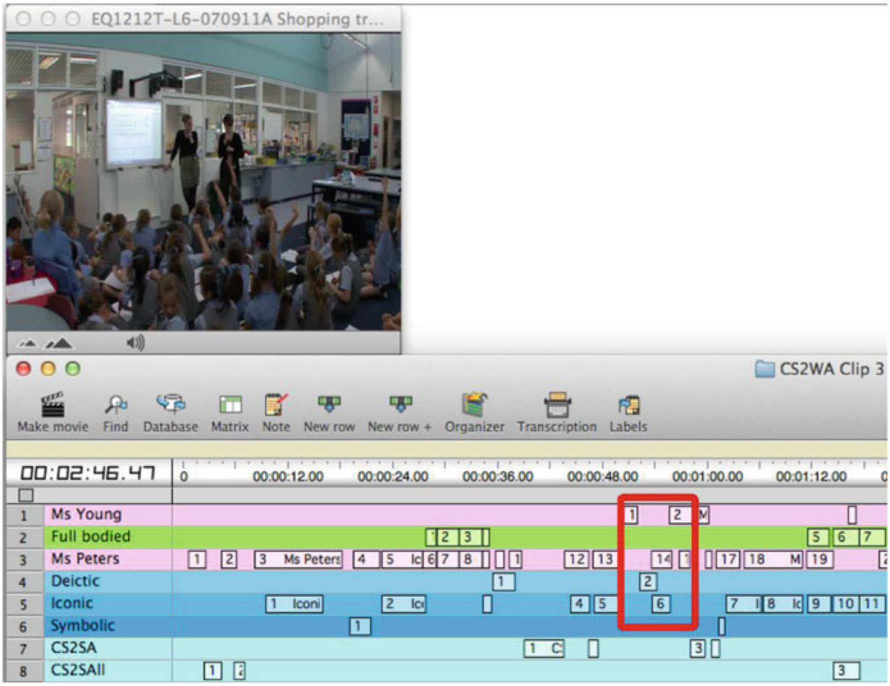


Fig. 8.2 Visual identification of simultaneous use of other modes with embodied representation (modal density) within *Studiocode*

This allowed the data to inductively inform how the different embodied representations influenced the scientific meaning that emerged within the interaction. The combination of deductive and inductive approaches to the micro-ethnographic construction (Erickson 2006) helped establish the scientific relevance of these embodied representations within the multimodal communication. The impact of the embodied representation on student learning was inferred from the affordances that shaped the on-going classroom conversation.

Emerging themes were identified within cases; these were then compared and contrasted with the use of similar embodied representational forms across cases to identify if any specific commonalities or differences could be distinguished in terms of such representational use across the different cultural contexts.

In summary, the analytic approach employed a deductive categorisation of instances of embodied representation that were used to facilitate learning. This was followed by an inductive generation of the role of the embodied representation in the generation of scientific meaning followed by a cross-case analysis of how embodied forms of representation were employed by teachers; either as a mode of communication or by requiring students to engage with such representation to facilitate learning.

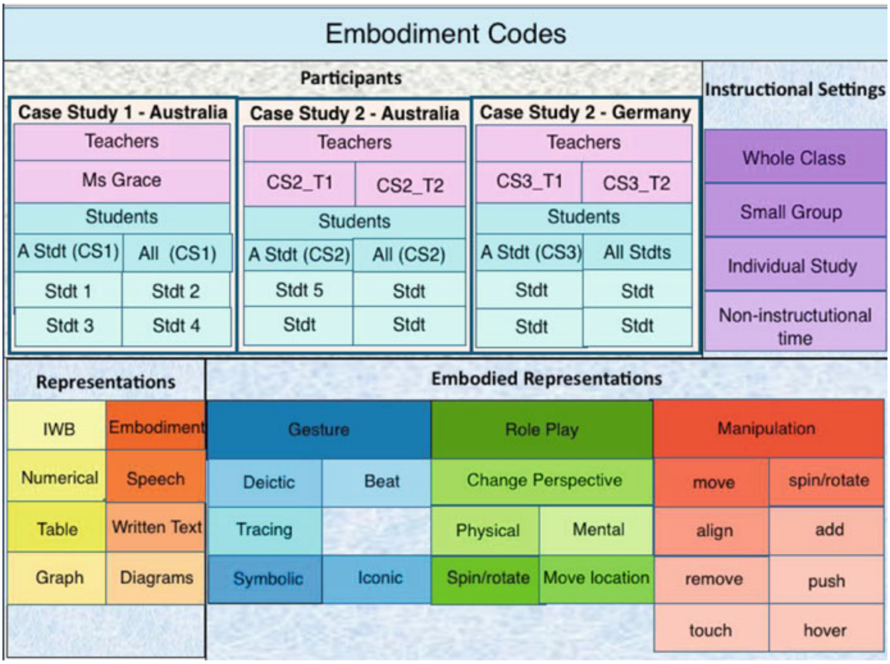


Fig. 8.3 Codebook showing embodiment codes and subcodes

Findings

In this section, vignettes are presented to illustrate how gesture, manipulation and full-bodied representation were used by teachers across the cases. Some interesting differences emerged in how the different forms of embodied representations were used and the functions they served within the multimodal sequences used by the teachers. As such, the findings describe the role of the embodied representation within specific vignettes and how the use of such embodied forms of representation produced specific pedagogical impact within the multimodal learning sequences. The cross-case findings and cultural implications are discussed in response to each representational form.

Gesture

Typically all teachers used deictic gestures to orient and point to salient information when explaining or communicating scientific ideas in the classroom. In all three case studies, the teachers used deictic pointing to perceptually make available material in the classroom such as a word on the interactive whiteboard, a part of a diagram or to parts of a model or equipment. The main pedagogical function being achieved through the pointing was to orient student attention to salient features, thereby refining and qualifying the scientific information communicated through other modes.

The teachers often used iconic representations to complement verbal discussion and provide visuo-perceptual links that enhanced the verbal description or explanation (refer to Chap. 7). In addition to such enhancement, gestures were used in a number of different ways; symbolically to invoke analogical meanings (as described in Chap. 7) as well as in 'beats' to provide rhythmic emphases to verbal communication. These generic approaches to using gesture for impactful teaching and learning were observed across all teachers in the three case studies in spite of cultural differences.

Vignette 1: Case Study 1 (Australia)

This vignette focuses on Ms Grace, a Year 4 science teacher who teaches in a government school in which the student population is largely multicultural with over 18 % of students with a language background other than English. She is informed by a constructivist view and believes that "every child learns in a completely different manner" and that "they need to be given the opportunity to develop concepts using different modes" of communication (from teacher interview). Many students in her class did not have well developed language skills to articulate their understandings clearly. As a consequence, Ms Grace often used gestures (deictic, iconic and symbolic) and other embodied representations to facilitate student meaning making.

This vignette illustrates how Ms Grace targeted the use of deictic gestures and integrated them into an opportunity for conceptual development across the last two lessons of a nine-lesson sequence on day and night. The students had discussed differences between day and night and had been outside in the school yard documenting the changes in length of a shadow produced by a 'shadow stick' at different times of the day in the previous lesson. Although the students were able to measure and graph the length of the shadows against time to develop an understanding of the size of the shadow, they could not attribute the changing length and direction of the shadow to the Earth's rotation in relation to the Sun.

After some discussion and attempts to help students with interpreting the graphs, Ms Grace highlighted the relationship between the position of the Sun, the opaque object (shadow stick) and the shadow it produced.

The teacher connected two different deictic gestures through her body and lined up the position of the Sun and the shadow so that the students could easily see how the direction of the shadow is determined through its connection with the Sun (Fig. 8.4). By identifying her body as the opaque object that stops light, and connected to the position of the Sun and the direction of the shadow, she was able to draw students' attention to the changes in the Sun's movement that caused changes in shadow length and direction (Fig. 8.5).

This 'gestural connection' was adopted by the teacher, based on her observation of the students during the activity with the shadow stick, from the previous day. In

Fig. 8.4 Position of the Sun

	Speaker	Transcription	Mode
1	Ms Grace	Now if your sun is over there where is your shadow going to be?	Speech
2	Ms Grace	Points with right hand diagonally upward in a 45 degree angle to the horizontal.	Deictic Gesture
3	Ms Grace	Stretches out her other hand in the opposite direction to her diagonally raised hand.	Deictic Gesture
4	Ms Grace	So why does your shadow change direction?	Speech
5	Ms Grace	Because the light is coming from a...	Speech
6	Ms Grace	Points to a student.	Deictic Gesture
7	A Stdt (CS1)	Opaque object	Speech
8	Ms Grace	'Cause you're an opaque object and the light is coming from a different direction	Speech
9	Ms Grace	Points down to her body using both her hands.	Deictic Gesture
10	Ms Grace	Points to an imaginary light source in the sky.	Symbolic Gesture

Fig. 8.5 Transcript – location of the Sun

the post unit interview Ms Grace recalled one of the students with “one hand up in the air and he [the student] actually makes a ball as if it’s the Sun, and he moves. He looks at where the Sun is now and he sort of moves his hand a little bit further and he looks down at the page and looks at his body and then uses that to help him make a prediction as to what happens”. When Ms Grace saw students struggle to make meaning of the shadow sizes with the graph and their inability to make sense of it, she remembered that “when they can actually get up and move and do things then it seems to be just that little bit easier” and decided to adopt the student’s approach.

Ms Grace used her arms to identify the position of the Sun in the morning by using her outstretched arm, and a verbal question. Once she established the relative locations of the Sun and the shadow, she identified the body as the shadow stick and as object that blocked the rays of light from the Sun. She introduced the link between the body and the arms as analogous to the connection between the light source, the shadow stick and the shadow.

In the next lesson, Ms Grace decided to make matters more concrete and address the students’ inability to make the link between the measurements of the shadows, the pattern evident in the graph and the movement of the shadow during the different times of the day as evidence of how day and night are caused. She made physical representations of the measurements of shadow length by cutting strips of paper to the desired length and organised them across a column graph to demonstrate the emerging pattern. Having established the pattern, she then started to check students’ understanding of the relationship between the location of the Sun, the object and the direction of the shadows produced by the shadow stick at different times of the day using that same gestural connection to remind them of how the Sun, the object and the shadow are oriented in relation to each other.

Ms Grace posed questions to prompt students to use pointing gestures to identify the location of East and where the related shadows were, asking them to “show me with your arms”. She also linked these gestures to true East and West to help students make links between their daily observations and the apparent movement of the Sun. She systematically used the gestural connection to help underscore the similarity in the shadow patterns observed at different times of the day.

At this point, she let the symbolic gesture demonstrate the connection between the relative positions of the Earth, Sun and the shadows produced in the morning and in the evening and used her speech to prompt students to think about the similarity by using the word “that” (Fig. 8.6). By using visual similarity and by rotating her outstretched arms, Ms Grace showed her students that although the shadows were produced in opposite directions in the morning and in the evening, they were produced by the same relationship. The light source, the object and the shadow were always lined-up.

Vignette 2: Case Study 2 (Australia)

In Vignette 2, Ms Young and Ms Peters used gestures quite differently to that of Ms Grace. They jointly taught their 60 Year 4 students in a room that opens out from both their classrooms in a non-government girl’s K-Year 12 boarding school. The students demonstrated a sophisticated command of verbal language in their learning; a combination of the high socio-economic background and the structured communication strategies used by the teachers.

The vignette is drawn from a series of extracts from Lesson five of a sequence of nine lessons. The students were being taught the concept of non-contact forces

	Speaker	Transcription	Mode
1	Ms Grace	What's similar about that!	Speech
2	Ms Grace	Stretches out her arms as she had done earlier when referring to shadows produced close to sunset.	Symbolic Gesture
3	Ms Grace	... and that!	Speech
4	Ms Grace	Turns and stretches out her arms as she had done earlier when referring to shadows produced in the morning.	Symbolic Gesture
5	A Stdt (CS1)	Umm..they are like facing the same way... except the shadow and the sun is changing it's directions?	Speech
6	Ms Grace	It's just changing different directions. So 9:00 o'clock ... shadow!	Speech
7	Ms Grace	Demonstrates the direction of the sun, and the direction of the shadow by stretching out both her arms.	Symbolic Gesture
8	Ms Grace	3:00 o'clock ... shadow!	Speech
9	Ms Grace	Turns around and faces the opposite direction to demonstrate the direction of the sun, and the direction of the shadow in the afternoon by stretching out both her arms.	Symbolic Gesture

Fig. 8.6 Ms Grace identifying how shadows are connected to the position of the Sun

through an exploration of magnetic forces after having explored contact forces such as pushes and pulls at some depth.

Although the students had sophisticated language skills and the teachers demonstrated a number of specific language-based structures that were built into the science learning sequence to help the students become effective communicators, the focus of embodied means of representation and communication remained a central focus. In the post-unit interview, Ms Young and Ms Peters had planned to use a kinaesthetic, language-focussed approach to teaching as drawing on students' body-based experiences and integrating them into the learning sequence so that the gesture were made symbolically and scientifically significant by providing "a name to what they were doing" gesturally. Similarly, Ms Peters emphasised that, "actually making them think about the doing so they can actually think about 'oh that's that! I can give that a name now'. That's what I'm doing … and so I just think that's really important". This vignette highlights, the teachers use of gesture include pointing and iconic use but also extends the symbolic use of gestures by introducing specific gestures almost as a language of sorts.

At the start of the lesson, in a whole class setting, Ms Young introduced and checked student understanding of magnets and their properties. Although students had discussed contact forces, inertia and momentum, this was the first classroom discussion on non-contact forces. As she rephrased students' responses to describe magnets, Ms Young introduced a gesture and touched two of her fists to emphasise that magnets "stick". Students then had the opportunity to share their understanding of magnets in pairs and report their partners understanding to the class. At this point in time, it became apparent that some students picked-up the proposed iconic gesture to articulate the idea that magnets have two poles. Others used this iconic gesture in tandem with verbal descriptions.

Fig. 8.7 Ms Young identifies poles with the two sides of her fist

As students started engaging with the discussion on magnets, Ms Young established a gestural language for describing the way magnets work. She identified the magnetic poles with two sides of her fist (Fig. 8.7).

As she spoke, Ms Young pointed to the thumb on her fist, identifying it as the North pole and providing students with the markers of how this symbol could be remembered. After she explained the difference between the poles, she checked to see if the students understood the difference by checking their ability to demonstrate their understanding through their own gestures (Fig. 8.8).

Once this gestural representation had been established, Ms Young then proceeded to encourage students to make predictions about what would happen if they brought two north poles together. She and Ms Peters worked together to model how to communicate their conceptual understandings of the repulsion force between like poles by bringing their fists together with a vibrating motion and holding them close to one another (Fig. 8.9). They also showed students how to demonstrate the attraction between opposing poles which enabled students to exploit this gestural language to complement their verbal understandings. The students used their imagination to draw more fully on the experience of the gesture by simulating grunting sounds when the gestures were required to be more effortful, invoking a deeper connection with the symbolic gestures. The teachers adopted these sounds and then proceeded to use them as the lesson evolved.

Once the teachers were comfortable with students' ability to utilise the symbolic gestural language, they then proceeded to use it as a trigger to have students interrogate their own conclusions to specific conceptual tasks. Later in the lesson,

	Speaker	Transcription	Mode
34	Ms Young	Fist up! This is your magnet. Let's see what you really know. This side...so the side that your thumb is on is the North Pole. That side...is the South Pole. Only your right hand. Only your right hand.	Speech
35	Ms Young	Points to her thumb on her fist and taps it with the finger of the other hand.	Symbolic Gesture
36	Ms Young	Points to the back of her fist where her little fingers are curled up. Students follow.	Symbolic Gesture
37	Ms Young	OK. North? Point to your North.	Speech
38	Ms Young	Touches the thumb end of her fist. Then repeats the touch when she asks the students to point.	Symbolic Gesture
39	Ms Young	Point to your South.	Speech
40	Ms Young	Touches the back of her fist on her hand.	Symbolic Gesture
41	Ms Young	North ... South ... North ... North ... North ... South	Speech
42	Ms Young	Repeatedly points to North and South end of her fist as she speaks.	Symbolic Gesture
43	Ms Young	Got it?	Speech
44	A Stdt (CS2)	Yup	Speech

Fig. 8.8 Ms Young identifying the gestural fist as a representation of magnets' poles

	Speaker	Transcription	Mode
56	Ms Young	Repel. Good. All right. Can you try with your partner and put your two North sides together?	Speech
57	Ms Young Ms Peters All Stdts	Both teachers bring the thumb side of their fists together. Students do the same.	Symbolic
58	Ms Peters	Good words	Speech
59	Ms Young	OOOOOOHHHHH! It is not working!	Speech
60	All Stdts	Students make grunting noises.	Symbolic Gesture
61	Ms Young All Stdts	Try to push their fists close to their parners with evidence of exertion on their faces.	Symbolic Gesture
62	Ms Peters	OOOOOOHHHHH!	Speech
63	Ms Peters	It's not working.	Speech

Fig. 8.9 Teachers model and students use gestural language

students were asked to try and use magnets to move toy cars that had magnets attached to their roofs (Fig. 8.10).

During this task, it soon became apparent that while students could get the cars to move alongside a ruler, they were unable to account for which of magnetic attraction or repulsion forces was causing this effect (Fig. 8.11).

As Ms Young came back to check on the group, she reminded the students of the rule they had established using the gestural language and asked them to test the outcome of two north poles together using gesture. The students were able to gesturally and verbally recall that two similar poles are unable to stick. Ms Young repeated this gestural revision for similar poles and, together with the students in the group,

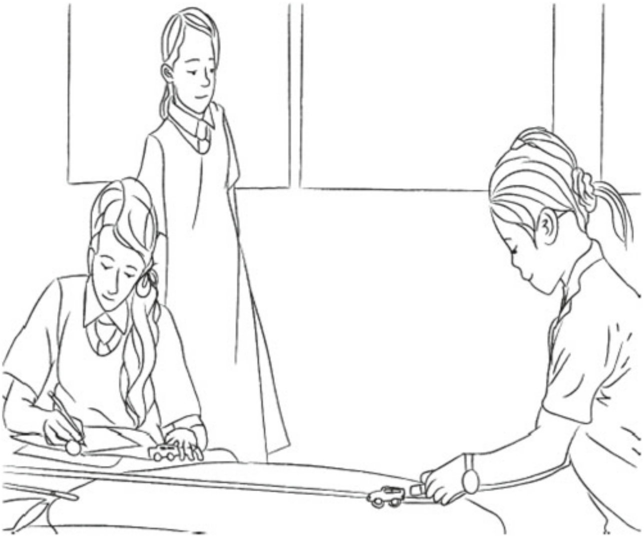
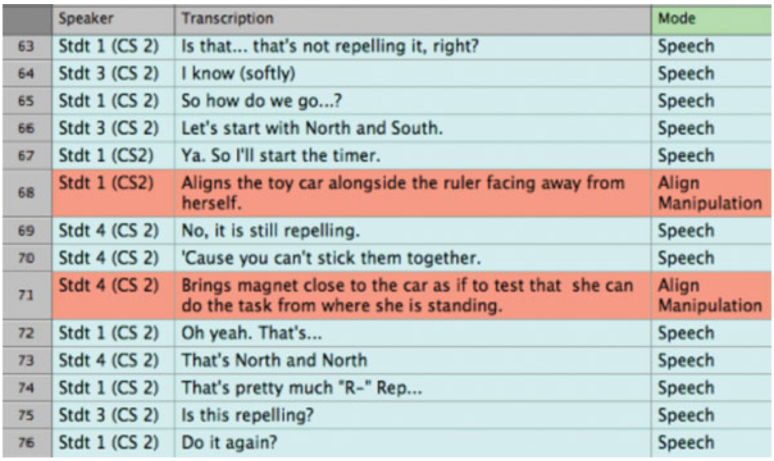


Fig. 8.10 Moving cars with magnets



	Speaker	Transcription	Mode
63	Stdt 1 (CS 2)	Is that... that's not repelling it, right?	Speech
64	Stdt 3 (CS 2)	I know (softly)	Speech
65	Stdt 1 (CS 2)	So how do we go...?	Speech
66	Stdt 3 (CS 2)	Let's start with North and South.	Speech
67	Stdt 1 (CS2)	Ya. So I'll start the timer.	Speech
68	Stdt 1 (CS2)	Aligns the toy car alongside the ruler facing away from herself.	Align Manipulation
69	Stdt 4 (CS 2)	No, it is still repelling.	Speech
70	Stdt 4 (CS 2)	'Cause you can't stick them together.	Speech
71	Stdt 4 (CS 2)	Brings magnet close to the car as if to test that she can do the task from where she is standing.	Align Manipulation
72	Stdt 1 (CS 2)	Oh yeah. That's...	Speech
73	Stdt 4 (CS 2)	That's North and North	Speech
74	Stdt 1 (CS 2)	That's pretty much "R-" Rep...	Speech
75	Stdt 3 (CS 2)	Is this repelling?	Speech
76	Stdt 1 (CS 2)	Do it again?	Speech

Fig. 8.11 Moving a toy car with magnetic repulsion

determined that opposing forces would cause the magnets on the car and in their hand to stick together. Having re-established this rule again, Ms Young asked them to try to move the car again while thinking about the type of force causing the motion.

The students confidently distinguished which of the forces were affecting the motion of the car and were then able to apply the concept of magnetic forces to real situations.

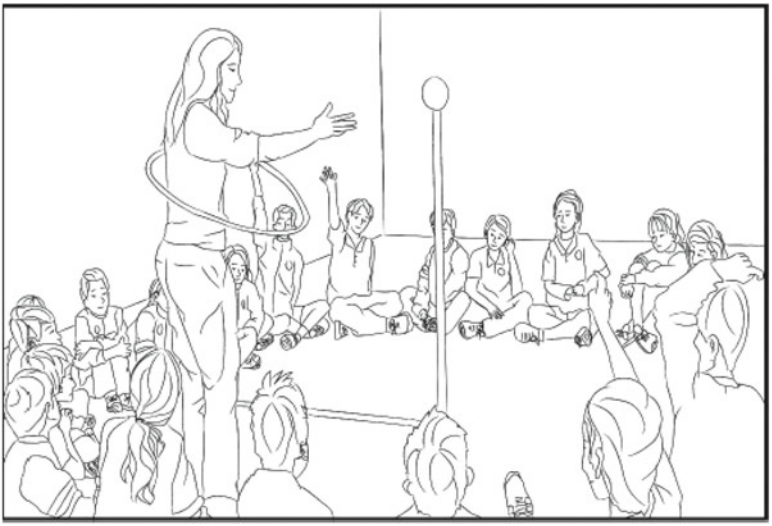


Fig. 8.12 Motion of the Earth round the Sun

Role-Play

The teachers in the different case studies also used role-play in very significant ways that were suited to their students' needs to make meaning around the scientific ideas being presented. Primarily, role-play was used to exploit the first-person visual perspective related to the prior experiences of students and teachers as well as the feelings associated with such perspectives. In addition, other representational resources such as speech were used together, to multimodally complement the role-plays. The variation in the use of role-play and how the pedagogical purposes were achieved are presented below.

Vignette 3: Case Study 1 (Australia)

This sequence of excerpts, highlight Ms Grace's use of role-play and its associated situated perspective to help students develop a heliocentric understanding of the Earth's movement around the Sun. She exploited the students' intuitive egocentric and geocentric views, proceeding to introduce allocentric perspectives to interrogate the intuitive view and introduce the required heliocentric perspective, all in a scaffolded sequence of embodied representations. In Lesson 4 of the sequence, after discussing their observations about the difference in night and day, the relative sizes of the Earth, Moon and Sun and that light travels in straight lines, Ms Grace invited her students to consider the motion of the Earth around the Sun.

She located a lamp in the middle of the room to represent the Sun and presented herself as the Earth by using a hoop around her waist (Fig. 8.12). She seated the

	Speaker	Transcription	Mode
1	Ms Grace	So if I went that... ALL THAT WAY around the Sun,	Speech
2	Ms Grace	Walks around in a circle with a hoop around her waist.	Move position Role Play
3	Ms Grace	Now remember. The Sun looks really really tiny when we look at it.	Speech
4	Ms Grace	Points toward the lamp in the centre of the 'orbit', pointing out the 'Sun'.	Deictic Gesture
5	Ms Grace	Holds forefinger very close to her thumb to show that the 'Sun' appears very 'tiny'.	Deictic Gesture
6	Ms Grace	So it's really far away.	Speech
7	Ms Grace	But it is actually really really big.	Speech
8	Ms Grace	Holds out both arms as if encircling a big object.	Symbolic Gesture
9	Ms Grace	If I did all of THAT in twenty four hours...	Speech
10	Ms Grace	Points to and virtually traces the circle around which the students sit and defines the 'orbit' of the 'Earth'.	Symbolic Gesture
11	Ms Grace	You and I when we walked outside would get very dizzy wouldn't we?	Speech
12	Ms Grace	Because the Earth would FLYYIING so fast..	Speech
13	Ms Grace	Stretches out a hand and moves it in an arc to annotate the word "FLYYIING".	Tracing Gesture

Fig. 8.13 Using visual-gestural narratives to explain the apparent size and motion of the Earth

students in a circle she named as the Earth's orbit by walking around it to specify the shape.

Ms Grace invited the students to imagine, what it might be like to be the Earth by describing what they would have seen and felt, in motion, orbiting the Sun (Fig. 8.13). She pointed to the 'Sun' and symbolically identified it's apparent size to provide a visual-gestural narrative to complement her verbal explanation of why it appeared so small in the sky. She then proceeded to further visualise why an observer on the Earth might be relatively confident that an orbit took much longer than 1 day. Using a deductive approach, she describes what might be seen should the orbit take a day. Using her tone of voice and iconic gestures to simulate the apparent movement of the Earth, she appealed to the students felt sensation of spinning to make the point that the Earth is in actual fact moving very slowly around the Sun. Although she did not extend this line of argument in any scientific way, the intuitive logic was based on iconic understandings and linked the scientific perspective to the student's prior experiences, making such logic accessible to them.

Ms Grace then placed four students inside the hoop to represent the Earth and then proceeded to engage their perspective of sunrise and sunset (Fig. 8.14).

Ms Grace asked the students to describe their experiences of alternate dark and light periods as they spun around near the 'Sun'. The students were able to use this role-play modelling of the rotation of the Earth on its axis to make sense of their everyday experiences of sunrise and sunset. By situating themselves in Ms Grace's perspective and those of other students they could make first steps to bring together

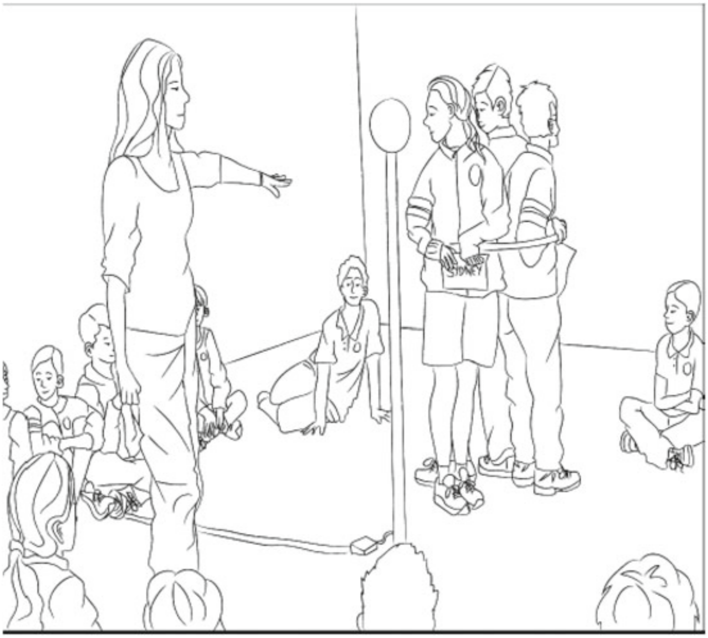


Fig. 8.14 Ms Grace demonstrates the perspective from the Earth

their own egocentric and geocentric views and appreciate the allocentric views that others might have, thus facilitating the possibility of adopting heliocentric understandings.

Later in the lesson, Ms Grace tasked the students in small groups to explore how they might model the relative positions and motion of the Earth and Sun and simulate how day and night were caused by using balls of different sizes and a torch (Fig. 8.15). After doing this individual exploration, each group had an opportunity to present their representation to the group. One small group found that they had difficulty explaining their model and Ms Grace stepped in to help. Meticulously, she started introducing and stitching together all the salient aspects of the model to help establish the 'building blocks' of information needed to help the students construct the scientific story of day and night. In many ways, by helping them enact and focus on the salient pieces of information required to build the scientific story, Ms Grace defined a 'conceptual workspace' that exploited students' embodied understandings of the phenomenon. Some of the 'building blocks' of the model were spatially relevant while others were temporally significant.

Ms Grace systematically asked students to identify and name which of the objects they represented. She used a constructivist approach to then gradually build a spatial model by asking each student, "Where should you be to show us day and night?" Step by step, she supported students to consider first person perspectives of each position, and then proceeded to establish the relative positions of the Earth,

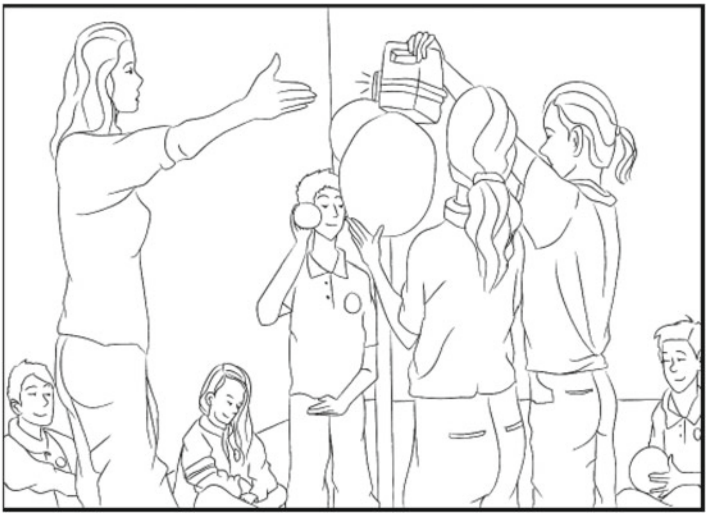


Fig. 8.15 Building a model of Earth, Sun and Moon

Sun and Moon. Ms Grace then asked the students to identify the dynamic elements of what caused day and night. She invoked the first person perspective that had been established through her modelling early on in the lesson to identify the effects of the apparent rising and setting of the Sun, and the students' individual perspectives to help them understand relative positioning and her position on the Earth by saying, "if I were here". This step-by-step movement between multiple perspectives and focussing student's attention on the dynamic aspects to enhance the use of models (See Chap. 7) helped the students exploit an embodied understanding to move back and forth between egocentric, geocentric, allocentric and heliocentric views enabling them to consider the scientific view of how day and night are caused.

Ms Grace's sequenced approach was intentionally multimodal. She used deictic gestures to point, iconic gestures to invoke imagery and symbolic gestures to link the scientific ideas to already available meanings at specific times to shape the students' developing understanding. Ms Grace also varied the function of her verbal contributions that foregrounded the salient aspects used by the varied representations, sometimes using it to support the main cognitive function that was met by the more embodied perspective-based, representations she utilised to teach day and night. In general, she used a perspective driven approach in a student centred and recursively elaborative approach to support scientific meaning making.

Vignette 4: Case Study 2 (Australia)

Role-play was also used by Ms Young and Ms Peters in their learning sequence on Forces in quite specific ways. They invoked students' prior experiences of the 'feeling of force' to distinguish how they felt when required to stop suddenly while they

Fig. 8.16 Embodied instruction

were walking compared to running down a hill. This fully embodied experience was exploited by the teachers in the second lesson of the nine-lesson sequence to help students situate their discussions of force in experiential memories of the concept.

To help prepare the students for the activity, Ms Peters used embodied representations in quite targeted ways to provide instructions before they went out onto the school grounds to complete the task (Fig. 8.16). She used pointing gestures to help them identify where they would start to walk or run and where they would stop, relative to their classroom location. She also provided iconic gestures and full-bodied representations by simulating how they needed to move as visual cues as she provided the verbal instruction.

The gestural and full-bodied representations were iconic as they accompanied Ms Peters' instructions, showing students what the task might look like when they carried it out and prepared them to focus on the feeling of running or walking down the hill. This embodied instruction was augmented by simulating scenarios so that the students' emotional response could also add to the felt experience. Ms Peters provided imaginary contexts for students to emphasise why they might need to run and stop suddenly even in mid-stride.

Ms Peters used gesture to indicate that the boundary was linear (Fig. 8.17, line 15), while the verbal statement highlighted the brick paving as this boundary. Her full bodied representation of the reaction to the body when stopping suddenly was indicative of the felt experience and anticipated the force that the students would feel when doing the task. She prompted an emotional response to stopping by 'transforming' the brick paving into lava and impressing the need to run fast by appealing to students' interest in dinosaurs and the fear it might invoke. Ms Peters also used beat like gestures to highlight the important aspects of her instructions.

	Speaker	Transcription	Mode
29	Ms Peters	Brings linked hands towards the ground and facing towards herself as if to define a boundary.	Symbolic Gesture
30	Ms Peters	Before you touch the brick paving.	Speech
31	Ms Peters	Leans in forward using the whole body.	Role Play Full bodied
32	Ms Peters	Holds up both hands linked and facing towards herself as if to define a boundary.	Symbolic Gesture
33	Ms Peters	The brick paving has become lava.	Speech
34	Ms Peters	Faces her palms down and moves them apart in a "spreading" motion.	Symbolic Gesture
35	All Stdts	A number of students produce gasps and various vocal sounds in surprise.	Speech
36	Ms Peters	And you are running ... from a Dinosaur.	Speech
37	Ms Peters	Points back over her should towards the top of the hill from which the children will start running.	Deictic Gesture
38	All Stdts	A number of students giggle and others laugh out loud.	Speech
39	Ms Peters	And so you've got to stop as ... as quickly as you ran.	Speech
40	Ms Peters	Motions with both clenched fists in front of her.	Symbolic Gesture
41	Ms Peters	Emphasises the words "stop", "quickly", and "as you" and "ran" by using moving the clenched fists	Beat Gesture

Fig. 8.17 Embodied instruction about how to run and how to stop

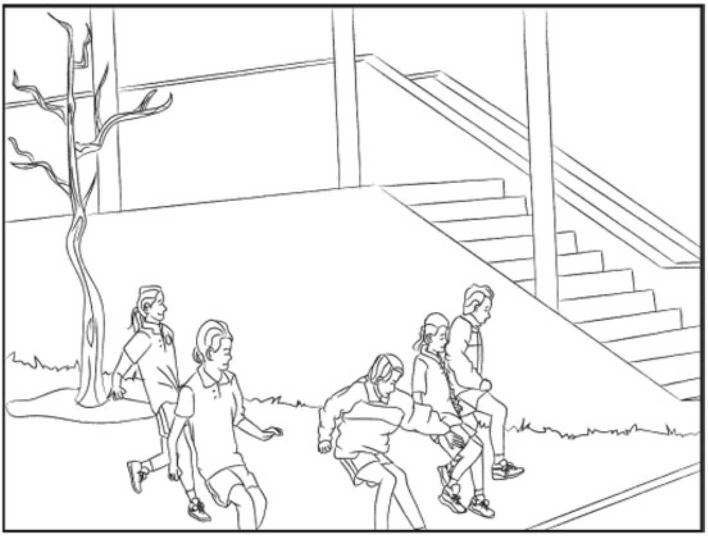


Fig. 8.18 Running down the hill

By using the visual, auditory and spatial cues as well as the contextual role-play references to imagined contexts, she orchestrated her use of the different forms of representation to invoke felt responses by the students.

Later that day, students went outside to do the task and run and walk down the hill (Fig. 8.18). Upon coming back to the classroom Ms Young helped students

	Speaker	Transcription	Mode
4	Stdt 1 (CS2)	Well, when you've... well, when I was running, I was running as fast as I could. And when I stopped, my feet stopped, but except it was hard for me to...	Speech
5	Stdt 1 (CS2)	Puts up two hands in front of her and simulates a leaning motion with the top half of her body	Iconic Gesture
6	Ms Young	Your body kept going? Like...like there would have been a little bit of this happening...	Speech
7	Ms Young	Spreads out her hands on either side and mimics falling forward.	Iconic Gesture
8	Stdt 1 (CS2)	Yeah.	Speech

Fig. 8.19 Using iconic gestures to remember

make sense of this experience by asking them how they had felt when running. She used iconic gesture to prompt students to remember what it had 'felt' like (Fig. 8.19).

Ms Young then asked students for a single word that they would use to describe the experience. The students indicated that they felt "pulled down" or that they were "putting a lot of force down the hill", but had difficulty collapsing the experience to one word. The students were then tasked with comparing this experience to their felt experience walking down the hill. They used words like "relaxed", and "normal" to identify the relative inertial force they experienced, coming to the conclusion that it felt "smoother" and "easier to stop" when they were walking down compared to when they ran down the hill. The students managed to engage with the concept of momentum with the teacher, extending beyond the curricular objectives in this instance. Further, the teachers' use of embodied instructions to provide clarity to students' tasks and the use of felt experiences to ground students' exploration of inertial forces was evident throughout this activity.

Vignette 5: Case Study 2 (Australia)

Ms Young and Ms Peters also used a full-bodied, imaginative role-play to help students understand that inertial forces were also at play when an object needed to be moved from rest. By asking students to imagine what it would feel like to push a shopping trolley that was full as compared to one that was empty.

The teachers used their hands, intonation and their whole bodies to model what it would feel like to push the trolley. Ms Young groaned as she leaned back and pushed, using her shoulders and her bent knee to provide students with a sense of a really heavy trolley (Fig. 8.20). Very soon, the students were groaning as they pushed their own 'heavy' trolleys with their arms pushing out in front of their bodies.

The impact of this imaginative, full-bodied, role-play further enhanced Ms Peters' explanation that the trolley was being pushed up a hill. Students were thus, able to draw on the experience of running and walking down a hill to make sense of the problem before them.

Fig. 8.20 Pushing a shopping trolley up the hill

	Speaker	Transcription	Mode
69	Ms Peters	What's...what's. Everyone. I want you to show me right now. Your shopping trolley	Speech
70	Ms Peters All Stdts (CS2)	Students and Ms Young hold their fists in front of them as if holding onto a trolley.	Iconic Gesture
71	Ms Peters	And you are trying to push it up a hill.	Speech
72	Ms Peters	Shakes her clenched fists to draw attention to where she is holding the 'trolley'.	Iconic Gesture
73	Ms Peters All Stdts (CS2)	Teachers and students lean back as if to bear some of the weight of the 'trolley' and push upwards with both hands and at an angle. Ms Young bends her knee as if to get more leverage.	Iconic Gesture
74	Ms Peters	Takes a step forward, bends her knees and leans back with her shoulders as she 'pushes' the 'trolley'	Role Play Ms Young
75	Ms Peters All Stdts (CS2)	Everybody sways back and then pushes the "trolley" up a virtual hill.	Iconic Gesture
76	All Stdts (CS2)	Students groan loudly as they push.	Speech
77	Ms Young	Groans loudly as she pushes the 'trolley'	Speech

Fig. 8.21 Recalling pushing a shopping trolley up a hill

Ms Peters used iconic gestures, shaking her fists (Fig. 8.21, Line 4) to draw student attention to the felt experience of pushing the imaginary 'trolley'. Ms Young augmented this multimodal experience for students by presenting a full-bodied representation of bent knees, leaning body and movement of the shoulders in conjunction with verbal groans to emphasise the effort needed to make the trolley move.

After students pushed their imaginary trolleys up and down the imaginary hill simulating the effort required to control the trolleys, Ms Peters posed the final problem by asking students if it would be harder to stop a heavier trolley than a lighter one as it moved down a hill. The students came to the conclusion that "it's [the heavier trolley is] harder to stop if you have to stop moving" because "it has lots of mass". By engaging with the simulated embodied experience, students were able to understand that mass was a factor that contributed to the inertial force. Ms Young and Ms Peters' use of verbal, gestural and full-bodied representations evoked students' prior experiences with pulling and pushing shopping trolleys induced a deep and robust understanding of the concept of inertial force.

Vignette 6: Case Study 3 (Germany)

The vignette described here took place in a mostly upper middle-class, private, co-educational school in Germany. Two teachers, Ms Lennard and Mr Arnold both had a history of leadership roles within the school and jointly taught a mixed group of 25 students aged 10–12 years in Grades 4–6 within their classroom. Together they had initiated teacher trainings in inquiry-based learning and the dialogic learning approach (Ruf and Gallin 1995) within the framework of the "prima(r)forscher" project to improve science teaching, which was implemented school-wide. The school follows a reform-oriented holistic teaching and learning approach.

The following events took place in the fifth lesson of a seven-lesson sequence that focussed on force. The teachers' aim was to enable the students "to experience force as a mutual interaction between objects" (pre-unit teacher interview) by enabling them to construct and test numerous hypotheses relating to forces and their physical effects, exemplified in this example by work done with levers.

Ms Lennard consciously provided many opportunities for learning by object manipulation and for students to demonstrate their knowledge when they made claims. In this vignette, she asked Samuel to "prove one more time what [he] mean[s]" when he described how a lever works. She prompted him to show what he knew using the materials available (Fig. 8.22).

As Samuel showed his understanding, he used very little verbal description. To indicate that it was a lever he was trying to place a wooden board so that half of it lay on the table and half over, he used a deictic verbal "this" (Fig. 8.23, line 3). When he moved the first cube to place one cube on the resting end (the one supported by the table), the position for balancing the board was articulated verbally as "here" and demonstrated by manipulating the object. Samuel indicated the likelihood that the board would not be unbalanced as a result of this action when he said "it is even safer" (Fig. 8.23, line 5). It is important to note that in these teachers' philosophy, scientific terms such as 'lever' should only be introduced once the meaning has been (literally) grasped (the German word 'begreifen' meaning 'to understand' has its roots in 'greifen' – to grasp). Thus at this stage (Lesson 5 of 7) the students had not yet been introduced to the terms lever and fulcrum. Although these terms were only introduced in the following lessons, Samuel demonstrated an intuitive and embodied understanding of how to balance the lever.

Fig. 8.22 Samuel demonstrates his understanding of the lever

	Speaker	Transcription	Mode
10	Samuel	Well, if I try to place this right in the middle...	Speech
11	Samuel	Using both his hands, the left to support the board, and the right hand to reposition the board, Samuel aligns the board so it is roughly half off the table and half resting on it	Align Manipulation
12	Samuel	if I place it on top of here it is even safer	Speech
13	Samuel	Lifts one wooden cube off the table with his right hand and decidedly, with some force, places it down on the cube on the edge of the board resting on the table.	Add Manipulation
14	Samuel	but if I place it onto here it automatically goes down.	Speech
15	Samuel	And places a cube on top of the single cube on the load edge of the board, causing the beam to become unbalanced tilt to one side	Add Manipulation
16	Samuel	He pushes the board down onto to the table to stop it falling down with his right hand and continues to hold the board down as he explains	Push Manipulation
17	Samuel	He uses his left hand to touch the free edge to give it stability	Touch Manipulation
18	Samuel	He lets go of the free edge but his hand hovers close to the free edge almost as if to protect against the board tilting again	Hover Manipulation

Fig. 8.23 Samuel's embodied understanding

Once Samuel established that placing cubes of wood on the end of the wooden board supported by the table would not upset the balance of the board, his actions indicated that he 'knew' what would happen if he placed an extra cube on the load end of the board, where the board hung off the edge of the table. What is of interest is the number of manipulative moves that he employed after his verbal explanation

	Speaker	Transcription	Mode
47	Ms Lennard	And when you talk about force, what do you change by...?	Speech
48	Samuel	He aligns the two cubes on the lever edge so they are directly on top of one another	Align Manipulation
49	Samuel	the weight of both sides is what I change!	Speech
50	Samuel	He takes a third cube and places it on the load end of the board (which has two cubes on each end) allowing it to tilt under the weight but does not leave the cube on the board	Add Manipulation
51	Samuel	I mean if I would place another one here again it would immediately fall down	Speech
52	Samuel	He removes the third cube from the board, leaving it balanced it again	Remove Manipulation

Fig. 8.24 Ms Lennard's scaffolding of Samuel's demonstration

(Fig. 8.23, line 7) that the move would cause the board to tilt. With his other hand, he pushed the other end of the board back onto the table, while touching the load end of the board to give it stability and then let go of it, but let his hand hover near the load end of the board in anticipation of it tilting despite his attempts to balance the board by pushing it down on the table. These moves indicated that he had a deep embodied understanding that pressing the board onto the table was necessary given that he now had two cubes on the load end and only one on the end supported by the table.

He then proceeded to add one more cube onto the end resting on the table as he held the board down. The timing of his releasing the end he was holding down after the forceful placing of the additional cube so that there were now two cubes on each end of the board, indicated that he was able to exploit the felt sensation of the board pushing against his hand to identify when balance of the board was established. Verbally, at this point, although Samuel emphasised that "…if I put one on top of here again it automatically stays a bit more" this verbal explanation did not demonstrate the subtlety of his embodied understanding evident in the intricate way in which he coordinated the actions of placing the cube and releasing his hand.

Ms Lennard interrupted at this point to ask a key question (Fig. 8.24, line 1). With the other students watching on, Ms Lennard carefully refocused the lever problem on the idea of balanced forces by asking Samuel to explain which kind of force was acting. The process of progressively increasing the number of cubes on specific locations on the board and the immediate effect of such movements was integral to the developing concept of levers although the term has not yet been introduced. However, the teacher's verbal emphasis on the terminology while Samuel manipulated the objects on the board, allowed for connections to be made between the terminology and the concept of levers in an illustrative and timely fashion due to the manipulative representations available in the process.

Although Samuel was then able to explain how the wooden board was balanced by focusing on position of the board across the table, and the fact that equal weights were placed on both ends of the board, he was unable to compare the forces that the cubes exerted. Mr Arnold refocused the students' engagement with the concept of force by asking questions like, "What can you say about the forces on both sides?" while Samuel continued to manipulatively demonstrate his understanding. Finally, when she asked him to compare the forces, he was led to verbally articulate that when the lever was balanced, the forces on both the ends were "equally strong".

Vignette 7: Case Study 3 (Germany)

Following the above activity, Ms Lennard and Mr Arnold took the students out into the yard where groups of students were given logs and a long wooden planks. The plank was to be placed on the log and to act as a lever. The students were asked to test the force needed to lift a student standing on one end of the plank in relation to where the plank was placed on the log. They were given the following challenge: "Can you raise your classmate off the ground by pushing down on the plank with only one hand?"

Norbert initiated the investigation designing an experiment in which two variables were considered; namely the length of the force arm and the position of the load (a student) on the load arm (Fig. 8.25). He started with the board placed so that the fulcrum was located halfway between the load and the effort. Ms Lennard asked Norbert, "What would you like to change so it becomes easier for you to lift Henry?" The use of everyday materials such as a plank of wood emphasised the real-life practical applicability of the physics concept.

Norbert considered the problem and explained that the distance of the load from the pivot point would need to be reduced either by having Henry move closer to the pivot point or by pulling the plank closer to him. Ms Lennard asked him to rearrange the situation as he saw fit. Norbert pulled the plank across to his side to shift the pivot point.

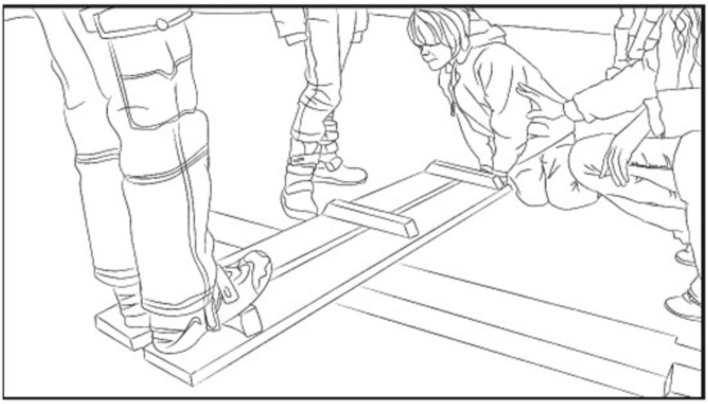


Fig. 8.25 Norbert trying to lift Henry using a wooden plank

	Speaker	Transcription	Mode
103	Ms Lennard	You did not change the weight	Speech
104	Ms Lennard	Points to the end of the leg next to Norbert's and traces a length in mid air to point to the pivot point.	Tracing Gesture
105	Norbert	I changed the length there and by that I also , ehm, also made it a bit easier so that I can press it down this way	Speech
106	Norbert	Presses the log down with his right hand	Push Manipulation
107	Norbert	Because then, ehm, because then I don't have to bring up so much force like THIS there	Speech
108	Norbert	Points to Henry's side	Gesture Deictic
109	Norbert	Ehm...THIS, the part Henry is standing on,	Speech
110	Norbert	Switches hand and points with other hand to the end where Henry is standing.	Deictic Gesture
111	Norbert	He pushes the log down with his other hand as he points with the other and speaks.	Push Manipulation
112	Norbert	To push it up.	Speech
113	Ms Lennard	She sits down and looks at what Norbert is pointing from his orientation then looks back at his face	Change Perspective Role Play
114	Norbert	Because it's no longer that heavy.	Speech

Fig. 8.26 Norbert's use of manipulation to explore forces while balancing a plank of wood

Fig. 8.27 Ms Lennard's pointing and tracing gestures

As Henry stepped on the other end of the plank, Ms Lennard pointed out that he had not changed the weight of the load to make the lifting any easier (Figs. 8.26 and 8.27). As she spoke, she used a pointing gesture and traced the length of the lever between Norbert and the fulcrum. This tracing movement clarified her verbal comment by visually redirecting the attention of the students around her to focus on what was salient to the effort required to lift Henry. Norbert was then able to articulate that he changed the force he needed to exert to lift Henry.

Significantly, Norbert repeatedly demonstrated the push and the effort required to both Ms Lennard and the other students by using manipulative representations.

	Speaker	Transcription	Mode
120	Ms Lennard	He said, he extended THIS HERE...	Speech
121	Ms Lennard	Points to the lever end of the log then points to the centre pivot point.	Deictic Gesture
122	Ms Lennard	Gestures a tracing action from the centre pivot point to the end of the log.	Tracing Gesture
123	Ms Lennard	And now try, if it's easier.	Speech
124	Norbert	Niorbert pushes his side down while Henry stands on the other edge. Nothing happens.	Push Manipulation
125	Ms Lennard	Still difficult. Change more.	Speech
126	Paula	I would say, Henry should go to the front a bit.	Speech
127	Paula	Points to Hernry.	Deictic Gesture
128	Ms Lennard	Henry's position is fixed.	Speech
129	Deictic	Points to Henry's position.	Gesture Deictic

Fig. 8.28 Ms Lennard's scaffolding students' understanding of the balanced plank

His words, "because then I don't have to 'summon' so much force" (emphasis ours) in conjunction with his pressing down on the lever to describe the size of the force needed (Fig. 8.26, line 107) indicates that he may have constructed the size of the required force in haptic terms. Norbert's reliance on this haptic and deeply embodied understanding was evident when he was able to articulate the connection between his end of the lever, Henry's position on the lever and the effort required to lift the load (Fig. 8.26, lines 109–114). By utilising the felt experience of feeling the force required to push the lever, and deictic gestures, Norbert was able to explain that it was "no longer that heavy" to lift up Henry.

Ms Lennard used this activity and its ability to draw haptic responses to help Norbert develop an intuitively embodied understanding of force to and articulate his understandings. She used Norbert's reasoning and representations to help the other students in the group focus on the issue at hand. She asked Paula if she understood Norbert's explanation. A shrug indicated that there was a little confusion as to what was meant. Ms Lennard then proceeded to scaffold the line of reasoning for those who were unable to follow Norbert's explanation.

Ms Lennard proceeded to use gesture to connect Norbert's verbal response to the objects in front of the students. To identify the extension of the distance between the fulcrum and Norbert, she first pointed to the two ends of this length and defined the new length of the lever arm between Norbert and the fulcrum (Fig. 8.28). As she had done earlier, Ms Lennard used the tracing gesture to draw the students' gaze along the length of the lever, outlining and foregrounding the full length of the new lever arm.

Once she had the students' attention on the salient aspects of the lever, the teacher asked Paula to try and address how to lift up Henry when nothing happened. By this time Paula was able to contribute to the discussion and proposed that Henry be moved. Ms Lennard used pointing to establish that Henry's position was going to remain fixed, limiting the number of independent variables and the ability for students to follow a single line of reasoning without confusion.

In this case study, the two vignettes demonstrate how object manipulation by students when scaffolded by the teachers' verbal and gestural prompts gave students the opportunity to explore and exploit the haptic experiences of forces and demonstrate their reasoning about, and emerging understanding of the principle of the lever through object manipulation.

Discussion

The three different case studies show how embodied representations in the form of gestures, role play and object manipulations were used effectively by the teachers, but in quite different ways to support students' reasoning and learning. The vignettes reported in this Chapter highlight the focus of this study on the forms of embodied representation that were used by teachers as well as how they were used across and between cases. Despite the variety, it is evident that each of the approaches was pedagogically informed and suited the specific scientific ideas under exploration. To respond to this research focus, we address the pedagogical functions intended and achieved through the skilful multimodal use of embodied representations by the teachers. The second research focus was to identify and account for cultural significance and patterns in the way embodied representations were used to facilitate effective science teaching and is identified within the cross cultural comparisons discussed below.

Pedagogical Functions Served by Gesture, Role-Play and Object Manipulation

In addition to providing general deictic and iconic references, gestures were used in very particular ways by the teachers of the case studies. In Case Study 1, Ms Grace gave the students the time and opportunity to personally engage with phenomena in an embodied way to ensure they had the experiences needed to underpin conceptual development. One of the ways in which she did this was to use the body's connection to the arms to link the alignment of the Sun, a shadow stick and its shadow. By picking up on the students' ability to intuitively engage with this connection, she utilised it in the following lesson to establish this link as a resource for students to identify that the Sun, the object and the shadow were always connected in a straight line. This embodied alignment enabled students to overcome the challenges of juggling separate pieces of information about the location of the Sun, the object and the direction of the shadow every time they needed to apply the concept. The ability to 'chunk' the information together provided a utility for students to predict and explain the movement of shadows during the day.

In Case Study 2, the use of gestures achieved much more communicative pedagogic function. The iconic 'language' that Ms Young and Ms Peters established helped students communicate their understandings by providing an embodied representation of the rule about attraction and repulsion of magnet poles. Students were able to recall the embodied rule and apply it to reason about and explain the movement of a car propelled by magnets. The teachers were able to prompt students to recall the rule rather than reteach it. As a consequence students became more independent learners as they applied their understanding of magnetic forces.

Role plays identified in the case studies had three different applications. Firstly, role plays were used to exploit the sense of visual perspective in understanding how day and night were caused. Ms Grace's structured sequence where her students were invited to view her, as the Earth, orbiting the 'Sun', view and interact with a group of their peers who were engaged in becoming the rotating Earth and to finally engage in re-representing the movement of Earth, Moon and Sun as a role-play. Through this sequence of experiences, Ms Grace helped them identify that they had an egocentric visual perspective that was different to the teacher's, then considered multiple visual perspectives by asking peers what they saw and finally by taking the perspective of either the Sun, Moon or Earth to develop a heliocentric understanding. Similarly, visual perspectives were used in the Taiwanese Case Study on this topic (See Chap. 7 for details).

In Case Study 2, role-play was used in one instance to construct a felt inertial experience when students compared what it felt like after running down and walking down a hill. The full-bodied role-play was constructed by providing an imagined context (running from a dinosaur and having to stop at the bottom of the hill to avoid stepping into lava). The pedagogical purpose of this activity was to provide a haptic experience and develop an embodied conceptual metaphor (Lakoff and Johnson 1999) to help students compare a very abstract concept that is hard to quantify at this level. This role-play was later expanded to invoke prior experiences of pushing a heavy shopping trolley up and down a hill. By connecting prior full-bodied haptic experiences through role-play, the teachers demonstrated an effective way of recalling prior haptic experiences. The teachers referred back to the embodied role-play experience to help students make sense of new situations.

In Case Study 3, Ms Lennard utilised manipulated objects to represent scientific ideas to students. By structuring activities that requires students to 'show' their understanding using several different levers, she provided opportunities for subtle aspects of students' understanding of balance to be evidenced. For example, when Samuel kept touching his wooden board, even though it was not stated, it became evident that he understood that the board was either unbalanced or at the point of losing its equilibrium.

In the second scenario, Ms Lennard provided an activity that required students to utilise their haptic sense and feel the resistance to the force, to provide a solution to the problem of lifting a student using only their hand on a lever. Again, the students were able to see the manipulation of the object as a visual three-dimensional representation, and to feel the resistant force as a tactile representation to help them understand how forces interacted when applied to levers. The teachers' use of pointing and tracing gestures in providing dynamic representations of manipulations refined many of the ideas students could access. As the levers presented themselves as a whole object, the pointing gestures were used to clarify positions, whereas tracing gestures were used to identify lengths of load and effort arms of the levers. This kind of tracing helped students to follow a line of reasoning.

In summary, each of the teachers used gesture, role-play or object manipulation as forms of embodied representation along with verbal communication forms to respond to the students' learning demand (Leach and Scott 1995) which arose from a deep understanding of the capabilities and needs of their students.

Variations Between Cases Set in Different Cultural Contexts

The variations in the types and ways of using different forms of embodied experiences across the cases needs to be set in the contexts of the wider pedagogical repertoires of the teachers and the cultural settings. The vignettes drawn from the two Australian cases feature teachers who use inquiry-based approaches and within these tend to use embodied experiences in teacher-orchestrated, whole class settings. Examples of this include: Ms Grace's engagement of the whole class in using the body to illustrate the alignment of Sun; and, Ms Young and Ms Peters working with the whole class to model the pole law of magnets and to recall embodied experiences of pushing a shopping trolley. These embodied experiences of phenomena were provided to students so they could use them as tools to reason about phenomena and to provide an experiential base for developing conceptual and verbally represented understandings of the phenomena. All students in the classes were engaged in these activities at the same time to ensure all had the same experience from which further discussions and learning could be based consistent with the inclusive ethos of Australian science education (as discussed in Chap. 2).

Ms Young and Ms Peters, also helped students construct a gestural language for representation and communication, and then provided a number of opportunities for students to apply the ideas in context with teacher feedback. This elaboration of the embodied perspective helped students to utilise gestural affordances to assign representational significance in symbolic form as a means for scaffolding students' ability to engage with the scientific terminology. Both teachers provided opportunities for students to articulate their understanding to one another using this symbolic gestural language.

The German case illustrates how the teachers provided individuals with extended opportunities to explore, reason about and explain the principle of levers through object manipulation supported by teacher prompting and scaffolding. These episodes were consistent with the teachers' broader pedagogical repertoires that often allowed students extended opportunities to demonstrate their thinking to the class using manipulation and speech. The philosophical views of these reform-oriented teachers were strongly influenced by Ruf and Gallin (1995). These influences were evident in the students first 'grasping' the notion of the lever principle through manipulation and haptic experiences before any scientific vocabulary was introduced to conceptualise their intuitive understandings.

The dialogic approach evident within the German Case Study benefitted from the embodied representations in a couple of ways. The physical representations of the objects being manipulated and the gestures of the teachers, enabled further ways in which the ideas of the individual students could be drawn out on the social plane of the classroom for the benefit of the individual and the class. Thus the manipulation of the objects and the verbal dialogue were interconnected by gestures which helped to clarify the meaning of the students' verbal utterances which were not framed using scientific vocabulary. When Norbert tried to lift up his classmate on the big wooden board in the school yard the teacher used her fingers to clarify the relevant variables that were changed in that situation. By a simple tracing action along the board with the fingers the teacher underlines the importance of the length of the lever arm thus scaffolding the dialogue about the relevant variables in the arrangement without even using the technical terms 'load arm' or 'lever arm' which were only introduces in the following lesson. In a way, the gestures stood in place of the technical terms as the teacher found it more important that the children first made the physical experience of the forces on a lever, before introducing the technical terminology.

While none of these studies are claimed to be at all representative of the specific culture, we make note of the way that the broadly framed cultural practices of teaching and learning within each school context influenced the ways in which embodied approaches were enacted. These cases illustrate that embodied practices tend to be nested within the broader pedagogical repertoire of the teachers, but with a deep understanding of the specific affordances each embodied form might provide for a particular concept. Therefore, we highlight the need for teachers to identify the pedagogic aims they would like the embodied representations to inform and the ways they might complement other representational forms that might be simultaneously at play.

Implications

The in-depth analyses conducted within this Chapter have identified some key aspects that inform the pedagogic use of embodied representations and inform recommendations for explicit and deliberate use of embodied representations to facilitate learning. Teachers in the three studies reported in this Chapter used embodiment to make connections between students' prior experiences and the new science concepts to be developed in meaningful ways. They considered the communicative significance of embodied representations as well as the conceptual affordances they provide for students to interpret ideas informed by first person perspectives. The vignettes illustrated how the teachers made complex and abstract scientific phenomena more 'real' and accessible to students; and, scaffolded personal embodied experiences to support students' reasoning.

Based on the findings, we offer some suggestions for teachers to effectively use embodied approaches. These include the need to:

- Consider the wide range of prior embodied experiences that students bring to the lesson that might provide the necessary analogical and directly perceptual conceptual resources that can be exploited for meaning making.
- Analyse the topic being taught for the productive opportunities to integrate embodied experiences (gesture, role-play and manipulation) that could scaffold student understanding.
- Understand how the embodied representation will afford specific understanding to students.
- Think through how these embodied representational resources can be used within the learning sequence to help students engage with more complex thinking and reasoning.
- Explore and identify the multimodal affordances these embodied representations can provide when used in other modal ensembles.

In summary, we emphasise the need for further exploration of the range of embodied approaches available within teaching and learning and how they might affect understanding, with specific reference to how each form of embodiment (gesture, role-play and manipulation) offers opportunities for student engagement with reasoning and meaning making. It is our expectation that further study of the implications of embodied understanding to specific science topics and ideas will reveal nuances that may help refine the discussion further.

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Part III
Meta-reflections on Teaching and Learning, and Cross-Cultural Classroom Research

Part III comprises three chapters which draw on the cross-cultural case study analyses reported in Chaps. 3, 4, 5, 6, 7 and 8 to develop reflections and insights into: the nature of reasoning and how it is supported by the exemplary teachers of the primary science case studies collected in diverse cultural contexts; characteristics of quality teaching as it is represented by the Australian, German and Taiwanese cases; and, the challenges of cross-cultural video-based classroom research and how they have been addressed in the EQUALPRIME project.

Chapter 9
Reflections on Reasoning

Russell Tytler

Introduction

A major aim of the EQUALPRIME project was to examine teachers' support of reasoning through identifying their productive discursive practices, and to explore commonalities and differences in practice that relate to the different cultural-historical traditions of the three countries. We have been exploring the forms of classroom discourse used in the different countries to provide opportunities for students to explore ideas, reason with ideas and evidence, and construct understandings about natural phenomena. This Chapter reviews the different analyses of teachers' support for student reasoning, described in previous chapters, in order to construct a more comprehensive view of reasoning in primary science classrooms, across these three countries.

Theoretical Perspectives on Reasoning

There has been increasing interest in reasoning in science classrooms relating to the promotion of higher order thinking and twenty-first century skills as important outcomes of education. These skills tend to be characterised by terms, such as critical and creative thinking, that are often also associated with reasoning. The TIMSS (Trends in International Mathematics and Science Study) characterises 'reasoning' questions as involving the following processes: analyse/solve problems, integrate/synthesise, hypothesise/predict, design/plan, draw conclusions, generalise, evaluate, and justify (TIMSS 2007). Peirce (1958) defined reasoning quite broadly as

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finding out, from the consideration of what we already know, something which we do not know. Peirce's view is quite productive and inclusive, amounting to characterising reasoning as 'moving thinking forward'.

While these are broad terms, they are useful in mapping the territory. They leave untouched, however, the question of the reasoning moves that underpin these processes in science and in science classrooms. In particular we are interested to analyse the relative importance of formal reasoning processes such as deduction, induction and abduction, and informal modes of reasoning including model-based reasoning, analogy and metaphor, and informal perceptual processes. In this Chapter we argue for a view of reasoning that is sufficiently flexible to capture the different approaches to teaching and learning and reasoning in classrooms from our three countries; which does not privilege particular modes of reasoning, or modes of demonstrating reasoning, that may be based in a particular cultural perspective.

Reasoning in science has traditionally been construed as involving relations between ideas and evidence and the ways these are coordinated. Thus, studies in the psychological tradition have been concerned with developmental aspects of the recognition and coordination of ideas with evidence in formal co-variation situations (Koslowski 1996; Kuhn et al. 1988), and the capacity of children to make this idea-evidence distinction (Sodian et al. 1991). In science education, growth in reasoning capability has been associated with the level of sophistication of epistemological positions (Driver et al. 1996). Tytler and Peterson (2003, 2005) describe three levels of epistemological reasoning:

- Phenomenon-based reasoning, where explanation and description are not distinguished, and the purpose of experimentation is to 'look and see.'
- Relation-based reasoning, where explanation is seen as involving the identification of relations between observable or taken-for granted entities rather than the searching for an underlying cause, and exploratory approaches tend to be confirmatory and uncritical. Explanation emerges from the data in an uncritical way.
- Concept- or model-based reasoning, where explanation is cast in terms of conceptual entities including models that represent an underlying cause or deeper level interpretation, where experimentation is guided by hypotheses, where the role of disconfirming evidence is acknowledged as significant, if not sought for, and where the possibility of alternative explanations is acknowledged.

More recently there has been interest in argumentation in school science, as a representation of the core process by which conceptual claims are established in science itself (Osborne 2010; Simon et al. 2006). These perspectives have underpinned some recent analyses of reasoning in classrooms. For instance Erin Furtak and colleagues (2010) argue for a framework to trace evidence based reasoning that includes the following dimensions:

1. Elements of reasoning, based on Toulmin's categories of premise, claim, and backing.
2. Quality of reasoning (claim based, evidence based (relational) and inductive or deductive (rule based)).

3. The teacher's contribution to reasoning (e.g. request for claims, request for backing etc.)
4. Conceptual level of reasoning (explicit vs implicit – the question of whether students simply reproduce teacher produced representations or ideas, or reframe language and representations in their own way)

Their highest level of reasoning quality involved backings based on generalised rules.

However, Shemwell and Furtak (2010) critique the use of argumentation as a sole indicator of or support for conceptually rich discussions. They argue that the types of classroom discussion that lead to rich conceptual ideas involves students grappling with new ways of looking at things, unencumbered by the need to provide evidence at every step. Student learning is not a straightforward rational process that occurs through the direct application of evidence to support new ideas. In looking at the particular analyses in that study, part of the reason for this mismatch between quality of argument and quality of conceptual discussion is the narrow way in which evidence is conceived of, as including only empirical classroom work concerning relations between factors. For instance the evidence admitted for arguing that floating depends on density amounts to narrow repetition of a rule (if density is found to be less than one it must float) whereas arguments with a basis in speculative explanation (it's got air in it, it's more spread out) are unacknowledged. Knowledge generation in science is based on much more complex idea-evidence relations than this.

In these cognitive traditions, reasoning has largely been characterised in terms of formal, syllogistic reasoning processes (deductive, inductive, abductive) that involve logics based on linguistic entities. However, Tytler et al. (2013) have questioned whether these formal logical processes adequately capture the reasoning processes that underpin quality learning in science, or indeed the reasoning inherent in the epistemic processes of science itself. On the first point, we have argued (Prain and Tytler 2012; Tytler and Prain 2010) that informal reasoning processes have an important role to play in students' learning of science, particularly highlighting the role of perception, and the central role of language, through metaphor and representation, in deliberative reasoning processes (see also Klein 2006). On the second point, we draw on a tradition of scholarship in studies of scientific reasoning, to argue that in science, informal modes of reasoning are critically important in idea generation and negotiation, associated with the imaginative creation of new modes of representation.

Reasoning Through Representing in Science and School Science

An important recent strand of analysis of reasoning has looked at the way models and representations are central to the knowledge producing processes of science. Model based reasoning (Lehrer and Schauble 2006), which involves students using

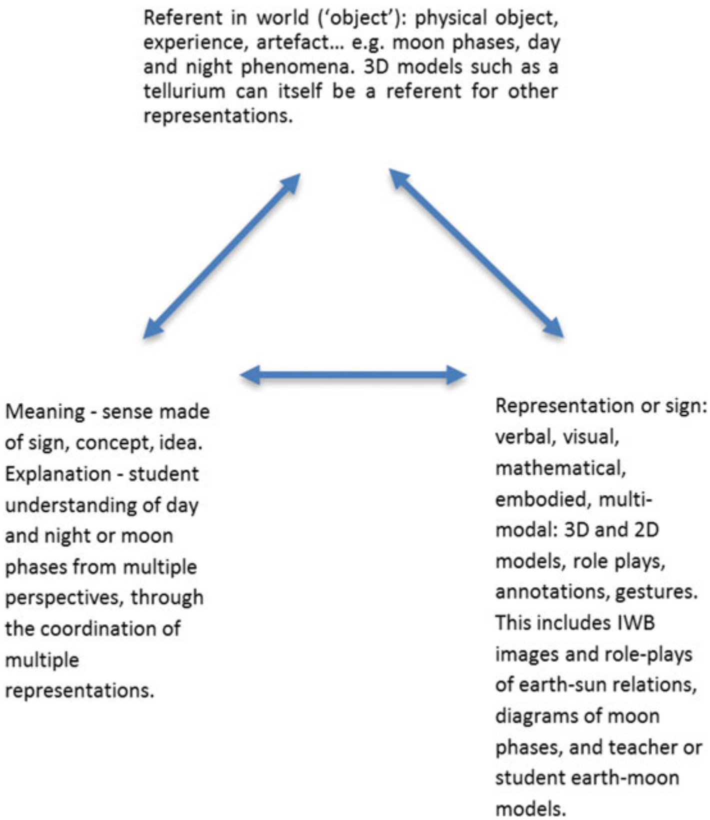

Fig. 9.1 Peirce's triadic model of meaning making illustrated for developing understandings of moon phases or day and night (Chap. 7)

and building representations to problem solve and interpret phenomena, has achieved increasing attention as we develop new understandings of the complex and informal processes of knowledge building in science itself (Duschl and Grandy 2008).

Tytler et al. (2013) have analysed student representational work largely through a Deweyan/Peircian, pragmatist perspective of applied problem-solving. They use examples of students' working and thinking to establish the close relationship between representations, their referents, and constructed meaning. Through these, reasoning is related to the Peircian triad of meaning making (Fig. 9.1).

Model based reasoning involves the construction and alignment of representations and models to solve problems or explain a target phenomenon. Tytler and colleagues (2013) argue that the construction of a representation constitutes a claim in that each representation involves selection and abstraction, and that use of the representation to construct explanations is an important mode of reasoning in science.

There is a growing literature on the role of representation, especially visual representation, as central to generating, coordinating and justifying ideas in scientific knowledge building processes. Gooding (2004) in his account of Faraday's notebook work, suggests that Faraday's development and modification of representations were critical to clarifying and instantiating his theoretical understandings and were part of informal reasoning processes by which new ideas were created. Latour's (1999) analysis of the process by which data are transformed through a series of representational 'passes' to build knowledge calls into question the possibility of a sharp and simple delineation between scientific product and the process through which it is developed, such that formal logical processes of justification of claims ultimately are subject to the contingencies of representational transformation processes. Clement (2008) in an analysis of expert problem solving in physics, identified a range of reasoning processes that he characterised as non-formal, used to tackle non-standard problems These included speculative modelling, analogy, and thought experiments.

Thus, particularly in the cases where students are engaging with models and visual representations, transforming between these, and constructing their own versions, student reasoning through representation is an important element of learning and problem solving.

Cross-Cultural Comparative Work

In analysing case studies of support of reasoning across different cultural and systemic contexts we need to be careful not to privilege particular traditions. David Clarke (2013, p. 7) challenges us thus: "How … can we undertake legitimate and useful international (and cross-cultural) comparisons when the act of comparison requires a preceding act of typification, which may conceal important explanatory detail? And, to pose another challenge: From the perspective of which culture is the comparative analysis undertaken?". Clarke argues that making generalisations about national patterns of classroom practice can be at the cost of explanatory power if we do not understand the particular cultural conditions underpinning the practice.

We thus need to take each case on its own terms and construct a view of reasoning that is multidimensional and admits a variety of approaches. For instance, in the three countries involved in EQUALPRIME there are differences in emphasis of teachers in supporting reasoning and inquiry. Broadly speaking for instance, the German teachers in these cases emphasise open class discussion in which students are encouraged and given time to generate ideas and communicate and negotiate these in public discussion. Teacher input is carefully controlled. In Australia there is an emphasis on hands on activities and collaborative group work, with whole class discussion dedicated to students voicing and refining their ideas. In Taiwan the emphasis is on efficient introduction of canonical science concepts where students learn the discursive forms before being challenged to apply these. Thus, in analysing ways the teachers support reasoning, we need to choose constructs that can adequately capture such practices in ways that participants would acknowledge, yet still allow some comparisons across the cases based on common constructs. To this end, the analyses in Chaps. 5, 6, 7, and 8 were all performed by cross-cultural teams, such that the data were subjected to scrutiny from the different cultural perspectives represented by the EQUALPRIME research team.

The analyses were emergent and reflect diverse forms of reasoning. They involve:

Teacher support of reasoning	Evidence of student reasoning
Identifying the particular ways the teacher moved students towards a more scientific understanding, in terms of longer term patterns across lessons and units, and the nature of the learning tasks	Evidence of students learning to problem solve and work with the discursive reasoning tools of science
Identifying the particular discursive moves through which teachers elicited and responded to student's ideas, and reasoning. This can be linked to Furtak et al.'s teacher support of argumentation	The quality and complexity of student responses, including argumentation moves
An analysis of the different semiotic tools with which the reasoning proceeded; how different representations were used and coordinated	Student construction, re-description and coordination of representations

Reasoning in the EQUALPRIME Cases

The cases presented below will draw heavily on the analyses performed in previous chapters, particularly the work on inquiry (Chap. 5), teacher discursive moves (Chap. 6), and reasoning through representation (Chap. 7).

The Taiwanese Teachers, Ms Hong and Ms Paulin

Both Ms Hong and Ms Paulin delivered very structured lesson sequences in Astronomy and Simple Machines respectively, supported by considerable curriculum resources, which they embellished with their own or the school's. In both cases the sequence was structured to efficiently introduce canonical science terminology and representations, and support students to work with these at a high conceptual level. Student reasoning involved responses to questions and activities designed to probe whether students could use these ideas in extended contexts, and whether they could interpret and identify patterns in activities such as the construction of a moon observation chart over a month.

In terms of discursive moves, both teachers made use of extending questions, which asked students to extend previous ideas to new situations, or interpret what is being displayed in a new way. Thus in Ms Hong's class, students were invited to look at an image of the Moon above the southern horizon, and were asked which way is East, and West. Ms Hong patiently invited ideas (mostly wrong), affirmed stories, and finally led them to realise a different way of looking at the direction.

Teacher: *Is your view the same as his as regarding the West? Is your view similar to his? I would like to ask one more student … Does anyone have ideas? Raise your hand if you have guessed the West. Let me just double confirm that you have guessed the answer.*
Well, there are other ideas. Please, go on.…

Student 1: *We are viewing the Moon looking South. So, the East will be here (left) and the West is here (right)*

Teacher: *We are viewing the Moon in the South. So, all the directions should be reversed.*
Do you understand what he has said? We are viewing the Moon in the South.
Hence, the direction that we are facing is …..?

Students (several): *It is the South.*

In this episode the student provides both a claim and backing in arguing that in looking at the image of the Moon in the southern sky, West must be on the right hand side rather than thinking of the image as a 2D map, with North being 'up' and West to the left, as everyone else in the class had assumed. In many cases in the Taiwanese lessons, however, the students were not asked to provide justifications but rather demonstrate their insights through short interpretive responses. Their responses were mainly very short in response to closely targeted questions, illustrated by the much lower student-teacher conceptual talk time ratios presented in Chap. 6. Here we see a clear cultural difference in that overt reasoning demonstrated in talk in Taiwanese classrooms is not as highly valued as it is for instance in the Australian classes or particularly the German class working on the topic of force. On an argumentation model, while both of the Taiwanese teachers challenge student responses there is very little challenge for students to overtly justify their claims, and the discussion moves quickly through canonical content. However, the reasoning involved in responding to questions, while implicit, is often high level. The broader pattern of the Taiwanese sequences involves closely scaffolded introduction of canonical terms and representations (the language of the lever, moon phase diagrams) leading through the sequence to more sophisticated models, and lever contexts requiring greater interpretation. The reasoning thus involves increasingly complex use of taught concepts and representations.

In the moon phase sequence Ms Hong from Taiwan supported students to reason by moving deliberatively between different representations, checking as she goes that students understand the nature of the models she is introducing, and how they translate from one to the other. The sequence is discussed in Chap. 7. Students are continuously asked to respond to interpretive questions about the models.

In the simple machines sequence Ms Paulin similarly crafted a strongly guided sequence in which students were introduced to ideas about levers and challenged to interpret these in a range of situations using a variety of representations. A characteristic of this sequence is the strong emphasis on control of scientific terminology, shown in Chap. 7. Ms Paulin introduced and reinforced the language and concepts of lever principles through challenging students to interpret increasingly complex

1. Probe student ideas about 'machinery', give tools/machinery to inspect in groups and introduce resources to overview functionality of machines.
2. Introduce see-saw idea. Students perform open task of catapulting eraser into a sink and discuss as a class. Experiment establishing the relation of forces in a lever to distances.
3. Introduction of terminology (resistance force and RF arm, fulcrum) and guided experiment using force measurement to establish relations.
4. Guided balance experiment using counterweights and spring balance, to establish relations of lever forces and arms.
5. Review and discussion of the results from the previous lesson and exploration of the pattern in the numbers. Students undertake questions from book and these are discussed.
6. Review of lever principles and introduction of different tools to extend the lever idea of force advantage and its application; scissors, pliers, ice cream spoons. Experiment to confirm force rules.
7. Groups are given tools to identify pivot point, application force point and resistance point, and report back for whole class discussion and review.

Fig. 9.2 Ms Paulin's sequence of activities concerning the lever principle

situations, supported by guided experimentation. Figure 9.2 shows the lever sequence in which probing of student ideas, open ended tasks, strong scaffolding of terminology acquisition, guided experimentation, and extension to a range of applications are all evident and carefully orchestrated. Each lesson begins with a review of the previous lesson's ideas. Following the lever sequence similar but shorter cycles of terminology introduction, guided experimentation and extension occur for pulleys, wheel spindles, and gear wheels.

Sequences of dialogue within each activity were strongly guided by the teacher, who continually questioned and challenged students to interpret simple machines using the established language and concepts. In the following sequence students discussed the result of an investigation of how easy it is to lift a puppet (named Xiao-Ming Wang) when it is at different distances from the seesaw pivot point. It is clear in this sequence that students were engaged with the question and felt empowered to challenge other students' responses. While Ms Paulin strongly structured the dialogue she left room for students to express their views.

Teacher: *OK, please to feel the difference of the force you applied when Xiao-Ming Wang is situated in different positions. I give you two minutes to experiment.*

Then, after this brief investigation

Teacher: *I would like you to speak up your findings. Ok?*
Student 1: *They are the same, same findings.*
Teacher: *Ok, please tell me. What is the feeling you have got in situation one, two and three. How do you feel? Think about it! S2.*
Student 2: *When Xiao-Ming Wang is nearer to the pivot point, it is lighter.*
Teacher: *Situation one or three? This? When Xiao-Ming Wang is nearer the pivot point, and …?*
Teacher: *Lighter?*
Student 2: *Lighter.*

Student 3: *It is not lighter*!
Teacher: *Ok*, *it doesn't matter*, *it doesn't matter. He said it is lighter. Do remember*! *When Xiao-Ming Wang is nearer the pivot point*, *it is lighter. OK. What else*? *S3*, *you disagree*?
Student 3: *Teacher*, *it is not lighter. It is just that the force you applied is less*.
Teacher: *Great*! *OK*, *but is what he said wrong*? *Actually*, *that is what general people feel. They often say that they feel it is easy and it is light. However*, *let me ask you. Will Xiao-Ming Wang's weight change while playing on the seesaw with me*?
Student 4: *No*.
Teacher: *Will you say Xiao-Ming Wang*; *you become lighter simply because he moves to here*?

The teacher moved the puppet Xiao-Ming Wang to make it closer to the pivot point.

Student 5: *No*.

The Australian Cases: Mr Roberts, Ms Grace, Mr Collins

Mr Roberts and Mr Collins in particular, of the Australian cases, structure their lessons with separate dialogic and authoritative episodes (Mortimer and Scott 2003). In Mr Roberts' case, as described in Chaps. 5 and 6, he moved between whole class engagement demonstration and discussion, to small group or individual hands-on investigation, back to whole class discussion where he strategically utilised students' ideas to shape their thinking and reasoning towards scientific conceptions. Figure 9.3 shows this sequence for a lesson on air resistance in flight.

Mr Roberts' skill in eliciting and affirming student ideas; then gathering these together in a public discussion, models and supports student reasoning.

Boy: *Floats*, *so it floats you down*, *that makes you slow down cause the air is trapped under the parachute*
Teacher: *The air is trapped under the parachute. So this one is dropping more slowly because the air is trapped*, *is that what you're telling me*?
Boy: *Yes*.
Teacher: *Harry*?
Harry: *It has more area to cover then if you hold it like that cause when you hold it like that*, *very slim*, *it doesn't take up too much air. But when you hold it like that*, *it covers a lot of area*.
Teacher: *Leah folded hers several times and she said it made it fatter…*
Leah: *…it made it thicker*.
Teacher: *Thicker*, *sorry wrong word. Thicker and the thicker one dropped…*
Leah: *…first*.
Teacher: *Did it drop because it was thicker or because it was … what was that word Harry*, *less area*?

Here we see student reasoning involving claims and justification based on general principles relating to objects moving through air, and Mr Roberts' support of this through probing of ideas, seeking clarification, and challenge as he teases out the competing explanations for drop speed. In the discursive moves analysis (see

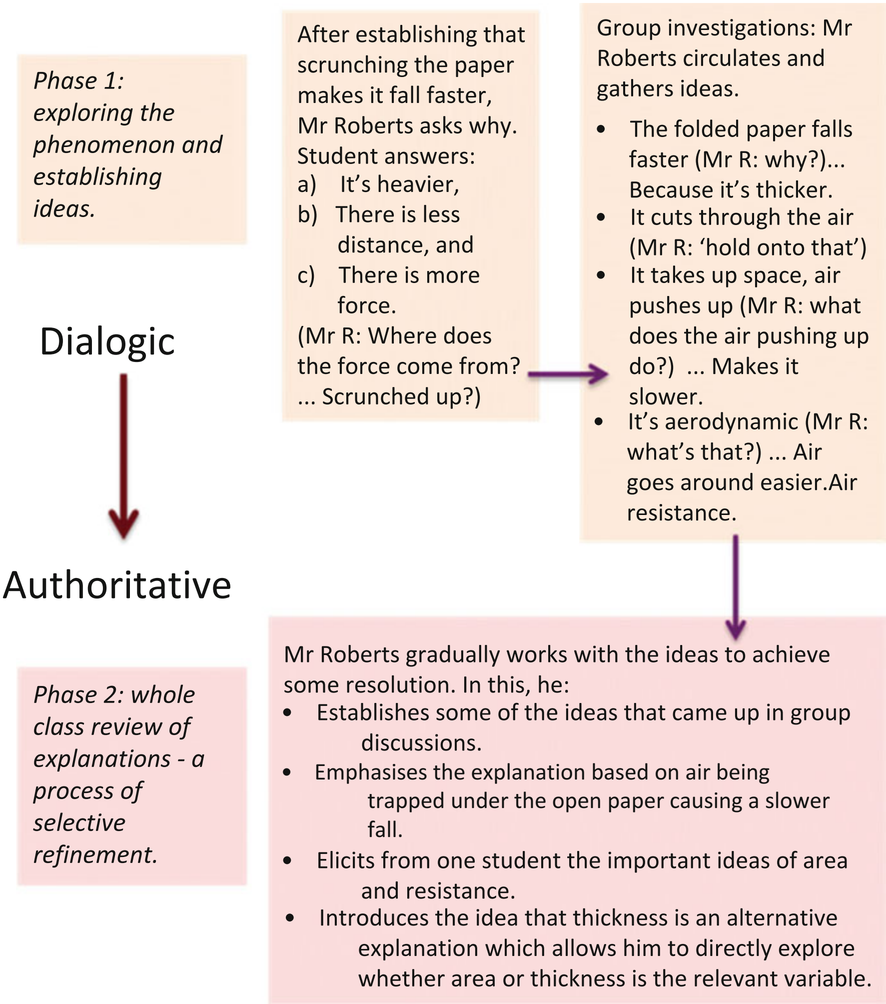

Fig. 9.3 Mr Roberts' typical activity sequence moving from dialogic (Phase 1) to authoritative (Phase 2) discourse

Chap. 6) we have an explicit unpacking of the means by which teachers encourage claims and backing, as described by the Furtak et al. (2010) analysis. As described in Chap. 5, Mr Roberts' practice is mainly centred around verbal and embodied representational modes, and hands on activities, with very little visual or spatial modelling to allow for students to translate between modes. In his case the reasoning is carried by this movement between talk, gesture, and hands on activity or demonstration, so that reasoning around representational re-description tends not to occur.

Mr Collins also moves from dialogic to authoritative episodes in his lessons, sandwiching exploratory hands on activity. This balance between whole class and small group talk, and exploratory (as distinct from illustrative) hands on activity, seems typical of the Australian case studies. Mr Collins' support of reasoning occurs often through an explicit strategy of challenging students' ideas (see Chap. 6) so that they are encouraged to justify their claims. The following excerpt from a lesson on the different states of matter is a typical sequence. Here, Mr Collins is challenging students' conception of a solid, following the reading of a formal definition.

Teacher:	*…yeah, wood is a solid, but I want to know why you think wood is a solid.*
Boy:	*Cause it's hard.*
Teacher:	*Cause it's hard, so…*
Girl:	*If a solid can't bend, a paper is a solid. That can bend.*
Teacher:	*ooooh, is there somebody already challenging thinking.*
Chas:	*Well a solid is something that is hard…*
Teacher:	*…something that is hard. Now Chas just said, if you're saying something is hard, what about paper, is paper a solid? No…*
Girl:	*…yes it is!*
Teacher:	*I'm not telling you one way or another. I want you to tell me.*
Girl:	*Not runny.*
Teacher:	*It's not runny.*
Boy:	*You can't put your hand into it like gas 'cause you can just…*
Boy:	*…you can't put your hand through it…*
Boy:	*… you can't put your hand through a brick so that is a solid.*

Mr Collins then retrieved a sheet of newspaper and offered it to one of the students to hold. He then punched his hand through the paper.

Teacher:	*Hold that. Hold it, I can put my hand through that! Does that make it not a solid?*

Mr Collins in this episode is supporting students to refine their classification of solids, liquids and gases by deliberately introducing difficult cases. In this way students are forced to clarify and rethink their categories. In this sequence Mr Collins showed many short videos and models of solids, liquid and gas behaviour and structure. He thus supported reasoning through representation interpretation, but did not have activities that required students to construct or coordinate representations. The activity sequences were reported verbally. Like Mr Roberts, the reasoning was mainly verbally expressed, but like Mr Roberts students engaged with open hands-on activities that required high level interpretation, claim making and justification.

In Ms Grace's sequence, which was analysed in detail in Chaps. 7 and 8, she was strategic in orchestrating multiple and multi-modal representations of the day-night cycle. She led students through these in a similar way to Ms Hong, constantly questioning students to check they were interpreting the models consistently, and engaging them in participating. She departed from Ms Hong's practice by setting an open model construction task that required students to actively generate claims concerning the balls they fashioned into a model, and link these to the day night cycle. When they did not do this at a deep level she intervened, modelling the interpretation of the model to explain the experience of day and night. The sequence is thus a good example of teacher scaffolding of multi-modal explanations, although it did not involve extended student reasoning to demonstrate their own coordination of these models.

The German Sequences: Ms Lennard and Mr Arnold, and Ms Petersen

The analyses in Chap. 6 of discursive moves in the two German cases shows a commitment in each case to extended student reasoning in whole class discussion, as students learned to communicate and respond to each other's ideas. Ms Lennard (T1) and Mr Arnold (T2) worked with their students on levers in a sequence described in some detail in Chap. 5. In the sequence they began with a stimulus photograph and gathered and developed student ideas through a series of experimental investigations, journal reflections and discussion. They, in particular, were very explicit in their commitment to working with the students' ideas rather than themselves driving the conceptual agenda explicitly. They did so by orchestrating student input, through strategically selecting student contributions to feed back into the discussion, by subtly re-representing the conceptual task, by framing exploratory challenges, and by helping students clarify and extend their ideas in whole class discussion and through responses to journal entries (see also Freitag-Amtmann et al. in press).

This movement of ideas in which teachers continually select and orchestrate student ideas to feed back into reasoning about phenomena, and experimental exploration is illustrated in Fig. 9.4. This is a simplified version of the more complete sequence built around the gondola problem, shown in Fig. 5.4 in Chap. 5. Figure 9.4 demonstrates the way student ideas were elicited, challenged, shared and refined in a cyclical process involving teachers strategically inputting ideas and experiences.

An example of re-representing is shown in Fig. 9.5, which shows an abstracted representation of the photograph shown in the first lesson, of a gondola supported on the side of a building. The students had speculated about the arrangement without a strong focus. In this case reasoned interchanges between students was encouraged explicitly, through the 'dancing chairs' strategy (Ruf and Gallin 1998) where students commented on entries in others' journals, and through the teacher-managed whole class discussion (described in detail in Chap. 3). This re-representation brought key features of the gondola structures into relief, which focused the conversation strongly on the lever elements.

Following a problem solving exploration where students explored arrangements whereby 40 blocks could be suspended with minimal counterbalance (see Fig. 3.7 in Chap. 3), the teachers posted photographs of students' experimental solutions on the wall (Fig. 9.6) so that the conversation was based on comparison and interpretation of the arrangements, again allowing free but focused movement around the Peircian triad of representation, phenomenon, and meaning making.

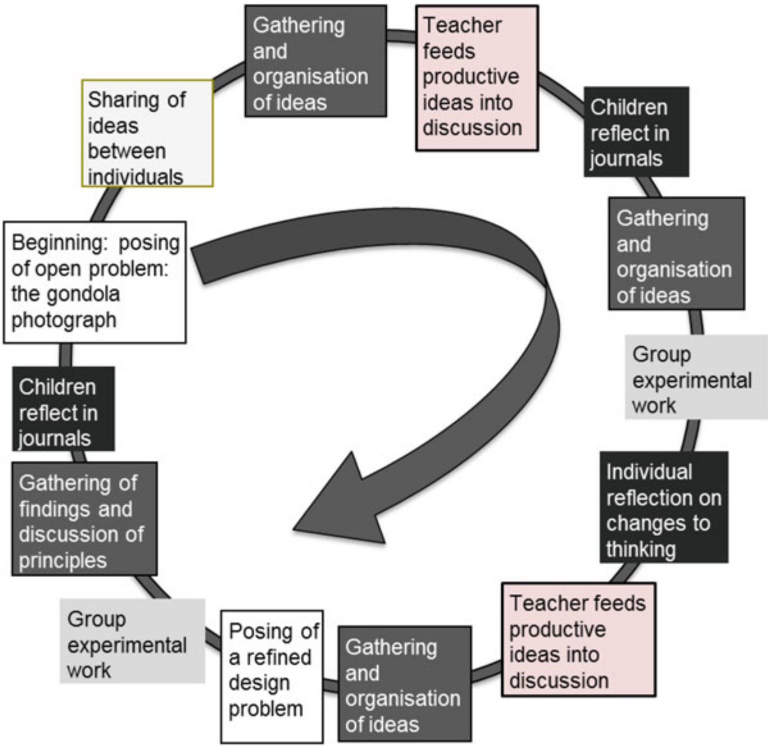

Fig. 9.4 Sequence of classroom activities and teacher strategic moves used in the gondola topic in the German class on levers

The posting of the photographs led to a whole class discussion:

Teacher1: *And was it like Jenny said that you had the bricks further in front*?
Student 1: *Yes*.
Teacher 1: *Aha*.
Student 1: *Yes. We had them about where the second one from the one at the back is*.
Teacher 1: *There*? *Ah*, *yes. Any similar experiences with where you placed the stones*? *Noel*
Noel: *We also placed them right in the back because in the front*, *well the fact is that in the front there is much more weight but in the back … it is somehow better because for example* [*if someone*] *wants to loosen the nut of a screw it is really difficult with a small screw wrench … and one can for example insert a metal pole and then*, *because it is longer*, *it is easier to do this as it is also easier for the poles to hold when it is further back*.
Teacher 1: *ok*
Teacher 2: *Aha*.
Teacher 1: *Sarah*?
Sarah: *One could also*, *if one does this* (*demonstrates with pen*!) *if one presses here*, *then it won*'*t come up easily. But if one presses here*, *it does so easily*.
Teacher 1: *Yes. Another experience. Yes. Dennis*?

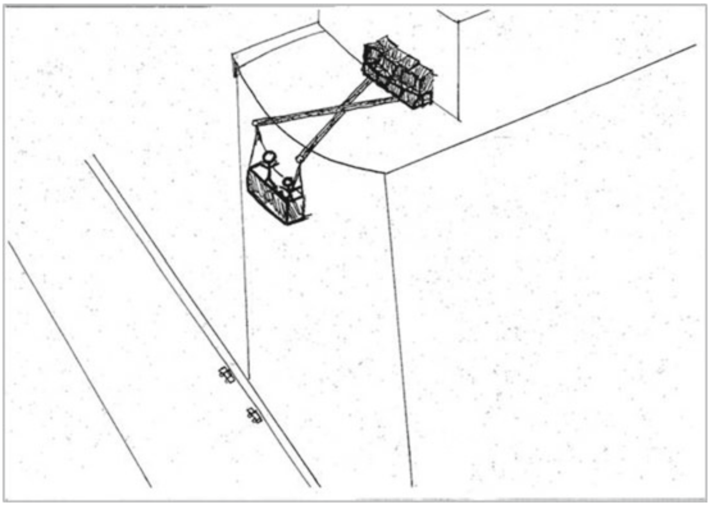

Fig. 9.5 Abstracted representation of the gondola photograph introduced in Lesson 2, exposing the lever elements

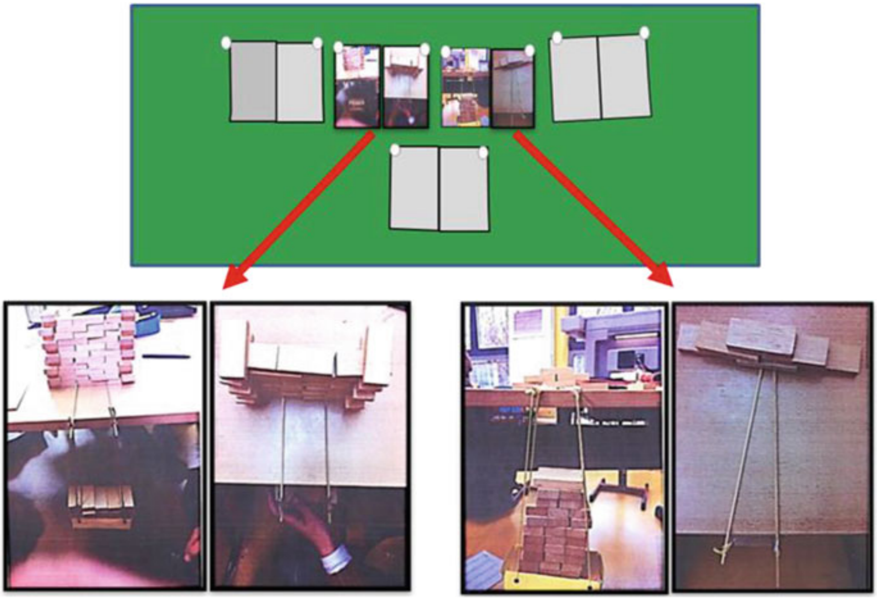

Fig. 9.6 Posting of photographs of students' experimentation for classroom discussion

Dennis: *This is also*, *for example like with the lever principle*, *if for example one wants to lift a tree with the help of a shovel and one digs it deep into the Earth and then lifts it*, *I mean puts it underneath*, *then it works better than if one puts it in only slightly and then tries to* "*lever*" *it out*.

Teacher 1: *So I gather the principle* "*further away*" *from your words*?

Dennis: *Well*, *not exactly. So that not much of the beam is visible at the end because otherwise it would come up*.

Teacher 1: *Patricia*?

Patricia: *But – to Dennis – that is really strange*! *The stones are at the back after all. And if it still works so well and there are more stones in the gondola than up then the stones could also lift it up. And then it would also not hold so well*.

Teacher 2: *Which picture illustrates clearly what Dennis was just trying to say*?

Patricia: *Well he just said that if one wants to uproot* (*lit. lever out*) *a tree one places the shovel inside and then one tries to lift it at the back. And if we take the stones here and the poles are up to here and the gondola is hanging from the poles and there are stones inside*, *then they could also lift it a bit easier somehow*.

This excerpt clearly illustrates the discursive moves the teachers made to encourage students to clarify and elaborate on their ideas about the forces at a lever, moves which were described in some detail in Chap. 6. These chart the diversity of teacher moves that conform to Furtak et al.'s (2010) description of teacher support for reasoning. There are several features in this excerpt that illustrate core aspects of the two teachers' practice in supporting student reasoning, which is different in type and scale to the other examples. The first is the respectful and inclusive stance of the teachers in participating in open speculation in a way that encouraged extended student interactions. They acted as conveners of a community of inquiry rather than the source of expert knowledge. Second is the success they had with encouraging elaborated student responses that included claims and justifications, using analogy, and speculative reasoned hypotheses with regard to what was going on. Their reasoning was at times relational and at times model based, as with Dennis's drawing on experience with shoveling to think through the gondola arrangement.

Ms Petersen's sequence on the phases of the Moon is not as complexly orchestrated as the Taiwanese examples, but also used open discussion that allowed room for student speculation and collaborative interchange to deliberately build understanding through a dialogic process. This can be discerned also in discourse around the tellurium:

Teacher: … *we still haven*'*t explained how the moon phases come about. Do you already have an idea now that you see this model*? *Paul*

Paul: *Ehm*, *if one switched on the light of the sun*, *one could turn the Moon*, *and then maybe the moon phases would appear*?

Teacher: *What do you believe*, *which moon phases you could show in which way*? *Do you already have an idea*?

Paul: (*inaudible*) *crescent*??

Teacher: *Yes*, *and how*? *What do you think*, *how would you see a crescent*?

Paul: *If the Moon turned this way*.

Teacher: *Well*, *position it*!

Paul: *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, Georg?*
Georg: *Well, I just had a thought, so, if the Moon is here in front of the Earth now and a ray illuminates this, I had a thought, that there could also be a solar eclipse sometimes.*
Teacher: *Mhh, ok*

In this sequence Ms Petersen challenged students to use the model to construct an explanation of moon phases, and then to be explicit about their claims through talk, and also physical demonstration of moon positions. Here we see support of argumentation around model based reasoning, with students making claims and justifying them through talk, and through model manipulation.

Conclusion

These seven cases all provide evidence of significant support of student reasoning, but in different forms and within different classroom traditions. In some respects the approaches to student reasoning and learning can be grouped by country, and the analyses in the earlier Chaps. 5, 6, 7, and 8 and this Chapter have identified dimensions along which they group. On the other hand, in both the discursive moves and representational reasoning chapters we have shown how there are significant commonalities, and on some measures teachers across countries have more in common than teachers within countries.

In comparing teachers working within different cultural traditions, researchers must inevitably take a perspective, and there is an associated danger in this; of adopting constructs that implicitly favour one country over another. I have argued in this Chapter that to undertake a cross case/cross country analysis of teacher support of reasoning that is respectful in acknowledging the core values underpinning different countries' practices necessitates the adoption of a range of perspectives. The way this is done must properly tread a line between dealing with constructs that can translate across cultures, and analyses that treat each case legitimately on its own terms. This Chapter has thus drawn on four different analyses of teacher support of student reasoning, to provide some assurance that the core practices are both properly represented, and in some way meaningfully contrasted. These analyses were of: (1) the structure of tasks and discourse across a lesson or lesson sequence, (2) teacher support of argumentation and student argumentation moves, (3) teacher discursive moves to support reasoning, and (4) teacher orchestration of multi modal representations and student coordination of these.

The analysis has shown some key teacher moves that are represented in some way by teachers in each country, that support student reasoning:

- Constantly monitoring and supporting and challenging students' ideas.
- Providing opportunities for students to speculate and hypothesise, and shaping thinking through a range of teacher responses to student input.

- Constantly requesting of students to make claims, clarify, justify and extend these.
- Withholding evaluation of student input and generating a classroom culture of engagement with ideas.
- Inducting students into the language and representational forms of science, through active involvement in their use.
- Challenging students to construct and/or interpret representations and supporting the coordination and evaluation of these.
- Supporting groups of students to collaboratively explore and generate ideas in the form of words and text, visual representations, and artefacts.

In this analysis the link between reasoning and learning becomes clear, in that the focus on reasoning amounts to a focus on higher level learning. To take a point from Peirce concerning the nature of reasoning, shallow learning approaches do not involve students constructing ideas that take them beyond what is already known by them.

A major dimension along with the cases diverge is the extent to which the teachers control the reasoning and learning agenda, such that extended ideas and conceptual moves are the province of the teacher, compared to students being challenged to speculate and contribute ideas that move well beyond what has been offered by the teacher. The first case represents the Taiwanese practice, and the second is best illustrated by the German case on forces. The Australian cases fall between, with student exploration and speculation but strong teacher guidance through introduction to tasks and input into discussion. These differences show in a number of aspects of the analyses:

1. There are many more episodes of dialogic discourse in the German and Australian episodes where students are invited to openly express ideas, whereas the discourse in Taiwan is almost exclusively authoritative even though students are constantly invited to contribute ideas, but in a more constrained way.
2. Student contributions to the discussion are shorter in the Taiwanese lessons and longest in the German sequence on forces where students give extended contributions that represent high level argumentation and abstracted reasoning.
3. Representations and artefacts used in the Taiwanese sequences, and to a lesser extent in the Australian sequences, are customised and canonical, whereas in the German sequence on forces and to an extent Ms Peterson's and Ms Grace's sequences students are challenged to produce their own representations.
4. The Taiwanese sequences take students more directly to the canonical science content, and generally to a higher conceptual level, than the Australian and German sequences, reflecting the more overt and structured teacher input.

Thus, while each sequence provides examples of teacher support of reasoning, there is a clear difference in what this means in each case. In the German cases there is a strong emphasis on students engaging in thinking through and constructing ideas jointly, with valuing of extended talk and interactive engagement. This is also true of much of the Australian cases, and mirrors contemporary western education literature arguing that deeper student learning flows from quality classroom talk. In Taiwan, however, talk is not so much valued compared to students' demonstrating the capacity to solve problems using canonical representations and processes.

Thus, it seems that the two Taiwanese teachers focus on providing students with the conceptual tools with which to reason, and the opportunity to practice these. For the three Australian and particularly the three German teachers the priority is placed on modelling the reasoning process. Students are challenged to create new ideas from what they know. In Ms Paulin's lever sequence, students create new ideas and processes only after they have been strongly schooled in the canonical representations (where is the fulcrum? Which is the effort?) with which to do this.

In order for students to reason scientifically, they need both the discursive tools with which to reason, and the orientation and processes to apply these in a problem situation. In the Taiwanese cases the emphasis is on efficient development of the high level conceptual tools, with which students can then reason. In the Australian and German cases, the emphasis shifts towards modelling the process by which the tools are developed, as an outcome of community reasoning processes.

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Chapter 10
Reflections on Quality Teaching in Primary Science Classrooms in Diverse Cultural Settings

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Introduction

Globally teachers are considered the most valuable resource in schools. They are key to implementing change and pivotal to improving student learning (Ingvarson and Rowe 2008; Goodrum and Rennie 2007). Recognising the link between good teachers and student learning justifies exploring the nature of quality teaching practice. The added value of international comparisons of classrooms provides opportunities to learn from each other about what we think of as quality teaching (Clarke et al. 2007). These reflections on quality teaching in primary science classrooms in diverse cultural settings aim to extend and sustain an understanding of good teaching practice.

The desire to better understand the nature of quality science teaching has been the main incentive for the EQUALPRIME project. The project looked at examples of best practice in science teaching in primary classrooms in Australia, Germany and Taiwan. However, while international studies such as TIMSS attempt to set global standards for quality science learning, perceptions of quality teaching differ not only among teachers but also among the research team members in this project.

The diverse cultural backgrounds of the research team members and diversity of the cases in this project provide multiple perspectives through which to explore

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teaching and learning practices in primary science classrooms. By examining the micro-culture of the classrooms, the project aimed to tease out the characteristics of quality teaching in each context. This Chapter draws on the data from Chaps. 2, 3, 4, 5, 6, 7, and 8 as well as on the records of the research team's conversations in joint meetings.

The Chapter is the product of the collaborative reflective process by all the researchers. The analysis has explored the organisational and contextual aspects of the cases in each country because these aspects provide insight into the nature of quality teaching in each country. Three cases, each described by a 'home culture researcher', paint a picture of the primary classroom, and the home researcher provides an interpretation of their selected case. The reflective analysis reports on the cross-case analysis which identifies six broad aspects of quality teaching. An example of this reflective analysis is presented, drawing on the three cases from the research (Table 10.1). This methodology constitutes a meta-reflective analysis of the perceptions of quality among research team members, exploring the similarities and differences in the perception and manifestations of quality in different local contexts and across them.

Purpose and Research Questions

The purpose of the Chapter is to reflect on the nature of quality teaching as perceived by research team members and manifested in practices among those teachers chosen for being 'good' teachers, in each of the three countries. It was not the prime intent of this project to identify quality teachers or quality teaching, but rather to look at those teachers who already have been recognised and acknowledged by their principals or peers as exemplifying good practice and examine their practice, with the aim to ascertain the characteristics of their teaching that exhibit 'quality' practice. The particular enactments of teaching and learning that are identified may represent different features of 'quality' in different cultures.

By identifying elements that are considered by the home researchers to represent quality teaching in the case studies from Australia, Germany and Taiwan, the cultural aspects and contextual factors that may influence the meaning of quality can be explored. The concept of quality teaching in science classes emerges through the analysis of data from all the cases each representing quality teaching in the EQUALPRIME project. The aim of this analysis is to look for an answer to the following questions:

1. Are there aspects of quality science teaching which can be seen as universal and independent of local culture and context?
2. What practices in the cases of the project differ, either in their presence or absence, or by the different emphases placed, that we could identify as culturally specific aspects of quality?

Table 10.1 Illustrations of five aspects of quality teaching in case studies from Australia, Germany and Taiwan

Aspect of teaching	Australian researcher comments on the Australian Case - Mr Roberts	German researcher comments on the German case – Ms Lennard and Mr Arnold	Taiwanese researcher comments on the Taiwanese case – Ms Hong
Engaging students	Mr Roberts showed a marionette puppet as a stimulus when introducing levers	The photo of the gondola was the stimulus that challenged and engaged the students	Ms Hong used the story of the bear to connect to students
Acknowledging children's ideas and providing feedback	Mr Roberts never passed judgment on the children's comments. He was affirming, with utterances like *"We'll have to test that idea"*. He cleverly orchestrated responses towards the scientific view	Mr Arnold did not correct the students, but through questioning directed their evolving thoughts in such a way that the students themselves came to a scientifically correct conclusion	Ms Hong communicated clearly to her students so they understood her thinking. To get feedback she often asked the whole class if they understood the science idea
The co-ordinated use of representations	Mr Roberts primarily used activities supported by verbal descriptions and placed less emphasis on student writing and drawing than is usual	Ms Lennard and Mr Arnold made use of several models and representations: pictures, drawings, self-made models, and life size levers in the schoolyard. The students recorded their ideas in their science journals	Ms Hong used multiple models and digital representations to help students understand the science ideas. Through questioning she helped the students connect the representations to their knowledge about the phases of the moon
Inquiry skills and inquiry teaching	Students made observations, predictions and tested ideas and were encouraged to draw conclusions based on the data collected	In addition to class activities, the students were free to bring in their own ideas and to experiment freely with the available material	Activities were integral to explaining science and Ms Hong scaffolded the students thinking
The use of dialogue and questioning to direct students' learning	Mr Roberts manoeuvred and directed children's thinking through the questions he asked. He listened carefully to responses and often responded with another question to promote thinking	Mr Arnold and Ms Lennard fostered extended discourse among the children by asking questions about their assumptions, observations and findings. The students talked about the science and explained their thinking	Ms Hong intentionally asked questions that fostered thinking, understanding and reasoning about the movement of the Moon

Background Information

Variation in the teaching practices across countries has been explored in international studies such as *Trends in International Mathematics and Science Study* (TIMSS) and the *Programme for International Student Assessment* (PISA). The analyses of the video data from the TIMSS studies showed that teaching "practices varied significantly across cultures and yet varied minimally within cultures" (Lyons and Niblock 2014, p. 68). The TIMSS videos revealed characteristic styles of teaching within the country-cases that were seen to reflect the culture of that country. In the comparison of data from the TIMSS studies, there is a tendency to look at the differences between countries, whereas both similarities and differences are needed to gain a complete picture of the teaching situation (Soh 2014). In the EQUALPRIME project, some of these similarities may prove productive in identifying elements of quality that are common across cultures. The nature of scientific knowledge implies a shared international understanding of scientific ideas. However, scientific knowledge is at the same time recognised to be culturally and socially embedded.

The TIMSS assessments, which are used for international benchmarking, are organised around two dimensions:

- a content dimension specifying the domains or subject matter to be assessed within science; and
- a cognitive dimension specifying the domains or thinking processes expected of students as they engage with the science content. (Martin et al. 2012, p. 6)

Although there is a serious critique of the logic and the use of data from TIMSS (e.g. Bracey 2000; Fensham 2007), the criteria used in the TIMSS assessment are often taken to represent the fundamental aspects of scientific knowledge and inquiry process skills. These are taken by the authors of the TIMSS study to represent a common ground for quality science teaching globally. There are five aspects of scientific inquiry process skills, which are used in the TIMSS assessment, that reflect the nature of scientific investigation. These are: formulating questions and hypotheses; designing investigations; representing data; analysing and interpreting data; drawing conclusions and developing explanations (Martin et al. 2012).

In Taiwan, the national curriculum is the fundamental indicator for teaching. The science curriculum includes both specific content and science inquiry skills. Teachers develop place-based curriculum (local), in order to respond to students' local (e.g., Indigenous) culture. Teachers provide experiential learning activities, and all content relates to the students' life experience.

In Australia inquiry teaching approaches that incorporate inquiry process skills have been advocated for some time (Hackling et al. 2001), and are generally agreed as being an important aspect of quality science teaching. However, teaching science as inquiry can be challenging, and Capps and Crawford (2013) suggest that it needs to be initiated by the teacher, modelling inquiry skills and scientific reasoning.

While inquiry-based learning (IBL) approaches are also considered as important in Germany, German researchers also point to other factors deemed important. Regarding science as a special type of language, both Ramseger (2013) and

Möller (2004) emphasise that making inquiries and doing experiments is not enough to promote scientific literacy; the even more important factor for gaining an understanding of the language of science is the reasoning process in the classroom. In this respect quality science teaching nowadays seems to be bound to a co-constructive approach to teaching and learning where the *scientific discourse* of the students is the core activity of meaning making, supported by targeted scaffolding by the teacher. Ramseger declares one overarching criterion of quality science teaching (Ramseger 2013, p. 169) is that: “Good science teaching enables the children to find an answer to a question about nature by means of independent reasoning, thereby strengthening their sense of self-efficacy”. Inquiry-based learning incorporating a focus on reasoning thus finds strong advocacy in all three countries, even though different researchers emphasise different aspects of it and the processes of inquiry take place in very different settings in the cases of our study.

The Reflective Process

The project compiled a number of cases from three countries. The cases are not claimed to be representative of the country. The research team comprises representatives from each country, each with individual perspectives on quality teaching that may influence the choices of the teaching episodes and the justifications for the teaching quality.

Most of the data were collected in Grade 4 classes; however, a few classes were mixed-grade classes. Four of the five authors have visited case study classrooms in all three countries and the other author has visited case study classrooms in two of the three countries. The visits have included observing lessons delivered in the classroom by a case study teacher(s), and talking to the teachers and students in the classrooms. These experiences have provided the authors with further insights to answer the research questions. A common micro-video ethnographic methodology (Goldbart and Hustler 2005; Erickson 2012), described in Chaps. 1 and 11, was used to make sense of the teaching and learning that occurred in these classrooms. Researchers have used three steps to achieve the cross-case analyses described in the previous chapters: individual case analyses, the sharing of all cases, and the comparison of cases. The analysis of video, artefacts, and interview data for each case were discussed during multiple conversations of the research team to synthesise the data and identify key aspects of quality teaching as represented in the cases.

This research process included the researchers meeting with some of the teachers and visiting classrooms in each of the three countries, the research team viewing and interpreting video data together, and the discussion of the representations of ‘*quality*’ in the cases, over the 5 years of the project. The progression of the analyses included deepening scrutiny of the cases and inclusion of an increasing number of cases as they became available. Cultural factors inevitably shaped the selection of data by the researchers who interpreted and assessed the data based on their culturally influenced standards, values and background knowledge. Issues of cross case analysis included: the focussing on class discourse over other data, generating a coding scheme that all researchers could apply; and, making inferences about reasoning by students, even if the response is limited and heavily scaffolded by the teachers. Discussing the cases together provided opportunities to exchange and discuss notions of quality teaching.

The "Home" Researchers Identifying Quality

As part of the reflective analyses described in this Chapter, a home researcher from each country (from the author team for this Chapter) selected one home case, analysed it in particular for aspects of quality teaching, and then shared these findings within the research team. Notes from the wider team, discussions concerning particular cases, recorded and transcribed at joint meetings are also part of the data set. Because teaching is embedded in a cultural setting, home researchers' analyses can be taken to provide privileged insight into the cultural setting and interpretation of the quality teaching practices of each case. In interviews, teachers were also asked to identify aspects of quality teaching. These were important data used to develop a collective understanding of the nature of quality teaching. This analytical approach aimed to identify cross–cultural insights and draw attention to the cultural differences that impact on the selection and description of examples of quality teaching (Clarke 2013).

Variation in the Context and Organisation of Teaching Science Across Australia, Germany and Taiwan

There are contextual elements that constituted important factors in framing how quality teaching is perceived and practised in each country. These factors varied across countries and more detail is provided in Chap. 2. They are mostly determined at a national or regional level by education authorities. These are important because they frame what is possible and expected in each setting. The contextual elements also reflect what each system values as quality teaching. They include the frequency and duration of lessons, the pace of lessons, the use of technological resources, teacher qualifications and expert knowledge, and assessment methods.

The Frequency and Duration of Lessons

Across the case studies more time was spent teaching science regularly in Taiwanese classes than in German and Australian classrooms. In Taiwan, at Grade 4 level, science is normally taught for at least three lessons of 40 min per week. Each unit or topic is taught for around 1 month; students will study four topics per term.

The teachers in Germany are free to decide how much time they spend on a lesson unit and science might be taught intensely for a couple of days or even weeks and then left out completely in the following weeks. In Australia, a survey of teachers in 160 primary schools revealed that science is taught on average for 42 min per week in Grades 3–4 (Angus et al. 2007).

The Pace of Lessons

The pace of lessons in Taiwan and Australia was considered to be very fast by the German researchers, and conversely the Taiwanese researchers considered the pace of the German and Australian cases to be quite slow. The video data allowed for the comparison of the number of words uttered by teachers and students in each case. The German cases had a higher percentage of student talk than the Australian and Taiwanese cases (Chap. 6, Table 6.1). The amount of talk among students and between students and the teacher could be indicative of students' opportunity and confidence to talk science. The analysis of the classes reveals a much higher mean whole class activity (WCA) time in the Taiwanese cases compared to the Australian and German cases (Chap. 4, Table 4.2). In Taiwan, when a teacher asked questions to the whole class the students raised their hands and replied in short sentences or phrases, often in unison, whereas in Germany and Australia, when a teacher asked questions to the whole class, individual students were nominated by the teacher and the whole class listened to the student's responses. Often other students stepped in and commented on previous utterances of their fellow students. The approach influences the pace that is achievable.

One Taiwanese teacher who observed an Australian classroom commented that in her opinion the slow pace meant that class time was wasted (August 2014, meeting record). The Taiwanese researcher explained that the pace in Taiwanese classrooms was not a product of a philosophical view but rather a product of the need to cover the necessary content to meet the unified teaching schedule of the school so students would perform well in exams (Minutes Nov 30, 2011). These constraints are not so evident in the cases of the other two countries where the teachers have comparably more freedom to decide how much time they want to spend on a unit. The German researchers explained that in the German cases the teachers proceeded slowly to ensure that all students would understand, working on the assumption that given enough time, all students will understand.

Availability of Technological Resources

There were more technological resources in Taiwanese and Australian primary classrooms in this project compared to the German case study classrooms. German primary schools do usually have computers in the classrooms at least at Grade 3 and 4, but generally computers do not play such an important role in primary education in Germany compared to the other two countries. In the EQUALPRIME case studies, the German schools did not make use of computers in the units analysed here. One of the Taiwanese schools had laboratories with projector screens and a technology room with computers embedded in each set of four desks, plus numerous computer touch screens on the walls for projection of information (see Chap. 3). In Australia the classrooms frequently had interactive whiteboards (IWB). The German municipalities are just beginning to equip more and more primary classrooms with IWBs.

Teacher Qualifications and Expert Knowledge

While some teachers of the EQUALPRIME classes were trained science teachers others were generalists with a special interest in science teaching. They all displayed a passion for teaching and learning and good pedagogical knowledge.

In Taiwan, primary teachers are basically trained as generalist teachers but many of them would have specialised training in a particular learning area, e.g., language, maths, science, social studies, or arts. The primary schools can decide by themselves whether they employ generalists or specialists for teaching science. Those who did not receive specialised training in science would undertake professional courses in teaching science in order to become qualified science teachers. In Taiwan, science at most primary schools is taught by specialist teachers. In other words, these teachers only teach science, even if a few of them sometimes need to help teach other courses such as physical education or social studies. As discipline specialist teachers, the Taiwanese teachers of our EQUALPRIME classes focussed only on teaching science and were able to refine their teaching of the subject matter as they often taught the same topic to different classes across the same grade. They also had regular professional development in science content and skills. The Taiwanese expert teachers involved in this project were also undertaking higher degree studies in science education.

In Australia and Germany at primary level, science normally is taught by generalist teachers who have comparatively less opportunities to expand their expert science knowledge. Increasingly, primary schools in Australia have a Science Coordinator who will undertake professional development in science education to gain the necessary skills for managing the science curriculum of the school and mentoring other teachers in teaching science (Campbell and Chittleborough 2014). In Germany all teachers are obliged to take part in regular professional development programs, but it is mainly up to them which subject area they choose for professional development. This means that many teachers choose other subject areas like language education or inclusion or classroom management so that they have never taken any courses in science or science education. Similarly, in Australia all teachers are required to undertake professional development each year, and the focus of the professional development is determined by the school or by the teachers. There is a comparatively greater focus on literacy and numeracy, than on science.

Assessment Methods and Functions

In all cases the teachers assessed students' understandings in relation to standards described in the curriculum by collecting evidence of individual student's abilities. However, there seemed a much more systematic approach to assessment in Taiwan compared to Germany or Australia. Taiwan has approved textbooks that are used in all classes. The assessment of the curriculum standards in Taiwan occurred at the class, school and national level whereas in Germany and Australia the assessments occurred at the class level only.

In Taiwan, there were multiple assessments: 40 % by school-based term exams, mainly paper and pencil tests; the remaining 60 % comprise a variety of assessment tasks, for example, performance assessments, worksheets or other supplementary tasks. The regular assessment by examination values and acknowledges student achievement. The importance of assessment in Taiwan is indicated by the parents' attention to students test results and the prevalence of 'cram' schools that students commonly attend outside regular school hours.

Testing in science appears to be less common in Germany and Australia with less emphasis on summative assessment compared to Taiwan. Evidence of students achieving the required standard is collected for assessment in Australia. Pen and paper tests in science are less common in Australia and Germany.

Examples of Quality in Different Cases

The significant variation in the contextual factors described above would seem to suggest an a priori presumption that teaching and learning in the three countries is driven by significantly differing values, and therefore a different framing of what might be considered quality teaching. In the analyses that follow we ask the extent to which this is the case, and whether there are some common aspects of quality teaching that somehow transcend these differences in contextual framing.

We first describe each Home Researcher's interpretation of their selected case, followed by the results of discussion and analyses within the team of aspects of quality teaching that are in some sense common across the cases. Each Home Researcher selected one case example of quality teaching drawn from the set of case studies from their country. The three cases thus selected are: Mr Roberts (Australia); Ms Lennard and Mr Arnold (Germany); and, Ms Hong (Taiwan) whose classrooms have been described in detail in Chap. 3. Each case presents background information, the teachers' beliefs drawing on interview data, and the Home Researcher's interpretation of those elements they recognise in the case as markers of quality teaching. Each case is described in the voice of the researcher.

Case Study One: Mr Roberts (Australia)

Mr Roberts is a mature science specialist teacher in a government school in Australia. He teaches science to each class for approximately 1 h per week. Mr Roberts is passionate about science and runs science and technology clubs in the school. He explained that the most important consideration is to engage the children, because without that there is no learning.

The quality elements of teaching in Mr Roberts teaching as seen by the Australian researchers included the way he led the class discussion to help students learn, the passion and enthusiasm he showed in encouraging student to learn science, the way he modelled scientific reasoning and the engaging hands-on activities in each lesson. Mr Roberts manoeuvred and directed children's thinking, listening, getting feedback from the children and giving them time to explore, and to learn (Chap. 5). Mr Roberts stated: "You've got to give the children an opportunity. You've got to challenge them in their learning".

He never passed a judgement on students' comments, but affirmed with utterances like "I like that", and "We will have to test that idea". He constantly asked questions and set challenges. Mr Roberts used strategies of revoicing, and rephrasing to encourage students to explain their science thinking. When a student made a claim he asked for a warrant or reason. He modelled scientific reasoning through talk (see also Chap. 6).

Case Study Two: Ms Lennard and Mr Arnold (Germany)

This case study took place in a private co-educational, denominational school near to Berlin, Germany. The school is a reform orientated school and has a holistic approach to education and emphasises inquiry and dialogic learning. Two teachers Ms Lennard and Mr Arnold co-taught the topic of forces. Ms Lennard expressed the view that "Our aim is that the children experience, understand this and that we can tell that they have understood something because they can consciously change parameters in order to change the action of force. I mean, extending the lever arm or force arm. And that one can take a reading of this afterwards." Her co-teacher Mr Arnold in an interview said that quality teaching had taken place when the children can make use of their insights in other situations. The philosophy of these teachers is of a holistic education with a focus on each learner developing foundation knowledge, confidence and skills. This is in compliance with the German ideal of 'Bildung', which has an emphasis on the individual learner's needs to develop as a future global citizen in addition to building independent learners, with the ability to have the confidence and curiosity to think for themselves (see also Chaps. 3, 6, and 8).

From the point of view of the German researchers, the elements of quality in this case included the use of the stimuli to provoke the children's sense of wonder, and an emphasis on the students' ideas and designs that were fostered through extended conversations in the lesson. Together with the children, the teachers formulated a question about the phenomenon in such a way that the children were able to find a meaningful answer. The teachers asked students about their assumptions, observations and findings. Students were encouraged to experiment with available material. The teachers did not correct every utterance by the students but through questioning directed their evolving thoughts in such a way that the students themselves came to a scientifically correct conclusion.

Case Study Three: Ms Hong (Taiwan)

Science is seen as very important in Taiwanese culture and in the school community (Chap. 2) and consequently it has a high level of attention in the schools. Ms Hong is a science specialist teacher at a large school in Taiwan. Her classes with around 26 children are held in a science laboratory or in an ICT supported room (see also Chap. 3) as well as outdoors. In this case, Ms Hong taught a unit about the movements of the Moon.

Ms Hong is the central figure in the class. She holds a microphone to her mouth and speaks quickly.

She also incorporates children books and video clips in her teaching. On a lesson in which she used a story called *Happy Birthday Moon* Ms Hong commented:

> I know the students may not understand the change of the moon's position… I use this lovely story [thus] stimulating students to think about the scientific explanation of the change of the moon's position. I hope they will think in a happy learning climate. (Teacher interview)

Ms Hong recognised that her students may find this topic difficult. She presented problems and explained how she encouraged students to "raise questions and to discuss with parents, teacher, or peers in order to solve the problem" (Teacher interview).

From the point of view of the Taiwanese researcher, the elements of quality teaching in this case are the way the teacher connects the content of science lesson with the students' everyday life experiences, the teacher's intentional use of questioning to foster thinking and the use of multiple representations and models to help students understand the science ideas. Ms Hong displayed good pedagogical content knowledge and technological pedagogical content knowledge. She was courageous taking on new and innovative challenges to improve her science teaching. She focused on equality, building confidence among all students.

Aspects of Quality Teaching

The case descriptions and interpretations described above, presented by the home researchers formed the initial stimulus for a wider discussion within the team that continued over a number of meetings. Out of this extended discussion a view gradually emerged of common aspects of all these teachers' practice. The discussion was enriched through visits to these teachers' classrooms in the three countries and discussions with them about their practice, and their context. These views were then articulated and refined by the authors who form a subset of the wider team, drawing also on the analyses described in earlier chapters of this book. An example of the cross-case analysis using the cases presented in this Chapter is presented in Table 10.1 organised under categories, described below, that emerged during these wider team discussions and subsequent refinement by the authoring team.

All teachers in this project have well formulated philosophies of learning, a passion for teaching and learning, a common tenacity at monitoring individual student's learning, they actively engaged the children in learning and all used a variety of representations to explain science ideas. Six common broad aspects of quality teaching have been identified from the analyses of the cases. These are: a commitment to engaging students, acknowledging students' ideas and providing feedback, fostering science inquiry skills, the use of representations in a co-ordinated way, the strategic use of questions and dialogue to direct students' learning, and understanding the needs of learners. There is variation in the way each of these aspects of quality teaching is demonstrated and this is discussed with respect to cultural expectations in relation to each aspect.

A Focus on Student Engagement

All the teachers fostered children's curiosity in a variety of ways; such as using a stimulus material, posing a challenge, discussing a conundrum. They drew students' attention to how the science they were studying was relevant to their everyday lives. For example, Ms Noone (Australia) used the question: "Water, Why should I care?" Mr Lennard and Mr Arnold (Germany) challenged children to explain how a gondola holding workmen functioned, a phenomenon that provoked the children's sense of wonder (Chap. 5). Ms Hong (Taiwan) used the picture book *Happy Birthday, Moon* as a stimulus to promote students' thinking about the Moon and to create a positive classroom climate. The challenge in the story is: Can the little bear put the hat on the Moon? This story helped students to think about the scientific explanation of the changing position of the Moon in the sky. All teachers displayed enthusiasm and expressed clear learning intentions. In Australia, Ms Noone expressed her desire to tap into children's natural curiosity by bringing "science questioning and exploration into my every day teaching because I feel like they're asking those kind of questions as 9-year olds anyway" (Teacher interview).

Monitoring and Acknowledging Children's Ideas

The teachers in the cases accepted children's contributions, and acknowledged the importance of children's thinking. Teacher-student interactions were used purposefully in shaping the construction of science knowledge. The teachers all modelled logical thinking and scientific inquiry. They often placed themselves in the position of a student, pondering and thinking as a student. Ms Hong (Taiwan) encouraged students to solve the dilemma of the direction in which the Moon rises and sets, through role play and questioning. She did not tell them the answer, rather confirmed the correct answer once their reasoning was correct.

Similarly, for Mr Roberts (Australia) questioning was seen as an important teaching strategy; he did not tell children answers. His teaching focused on developing children's skills in learning how to think. Mr Roberts explained that children don't learn concepts instantly, so he provides learning at different levels and returns to ideas so students could have opportunities to develop understanding.

In Mr Collin's class (Australia), the children made a shape of a triangle on their foreheads, using their hands to signify that they understood or agreed with the comment that was being made by another student.

In their science and maths lessons, Ms Lennard and Mr Arnold (Germany) follow the concept of dialogic learning according to Ruf and Gallin (1995). As Mr Arnold explained in the pre-unit interview:

> We try to introduce a phenomenon and the first step is: how to enable the children to relate to it. There are no right or wrong answers. … And we would then try to direct the attention to whatever leads to the physical phenomenon. Without pushing other things aside or discrediting them, because they are also valid. But we do focus on the physical core of the matter. … So, Dialogic Learning is an important anchoring point for us. … I mean, to us, natural science has less to do with formulas and completing work on certain rules. Rather it is a kind of process of mutual understanding. … There are different views on this [phenomenon] in the argumentative discourse: How do I see this, how do you see it? A kind of comparison. (Pre-unit teacher interview)

In an interview, Ms Hong (Taiwan) explained her teaching approach: "I diagnose the key points which students find difficult, and prepare appropriate materials and methods to scaffolding their learning; 'spiral teaching' is necessary for students to construct understanding, and enjoy their learning". The case study of Ms Hong is presented in Chap. 7. It shows that she was energetic and enthusiastic about teaching science. She was courageous taking on new and innovative challenges to improve her science teaching.

The high level questioning skills by all the teachers in the case studies were significant in moving student's thinking towards the scientifically acceptable ideas. There is similarity here in the positive and affirming approach all the teachers used. The strategies the teachers used were also important for monitoring students' understandings and revisiting science concepts and ideas as necessary.

The Coordinated Use of Representations

Representations include any type of communication e.g., verbal, written, visual, embodied, and mathematical. In the cases there are multiple examples of written language, gestures, and models being used to promote scientific understanding and develop scientific literacy skills. The lessons in the Australian and Taiwanese cases had multiple changes of activities and tasks (Chap. 4) with an expectation of the use of multiple representations.

The type and use of representations varied among the teachers in this project (see Chaps. 7 and 8 for more detail on representations). Conversations are pivotal to the exploration of ideas as children observe, write, experiment, test ideas, record and present results. Mr Robert's classroom (Australia) contained many scientific artefacts, models and posters representing science ideas to foster children's interest in science (for more details see Chap. 3), but in his class he mainly focussed on verbal representations of science understanding.

While some teachers focussed on one or two types of representation others used multiple representations including different modes. For example, Ms Hong (Taiwan) had the students undertake a role play of the phases of the Moon using a light source for the Sun, a student representing an earth-bound observer and another representing an astronaut, and used animations of the phases of the Moon and static diagrams (see Chap. 7 for the transcript of this excerpt). The German cases also used multiple representations, but spent longer periods on each task. In Ms Noone's class (Australia) as well as in the German class that worked on forces, the students used science journals to reflect and to wonder. Commonly, whole class and small group discussion would precede the writing, providing opportunities for students to think and talk about their understandings before writing and drawing. Ms Noone provided the beginning of sentences, e.g.: "*What I have learned about change is …", "I know this because …", "I want to know more about…*" (Fig. 10.1). Similarly, Ms Sands (Australia) used phrases such as: *What am I looking for*? (WILF) and *This is because* (TIB) to provide metacognitive scaffolding for students (Hackling and Sherriff 2015).

Digital modes of representations were used in the classrooms. In Taiwan and Australia there were many examples of the integrated use of digital technology in teaching. For example, Ms Hong used a digital timetable of moonrise and moonset to help students compare the time difference of moonrise and moonset on different days. In Mr Robert's class (Australia) the children used digital light sensitive data loggers to record the speed of a ball falling down a slope and in Mr Collins' class (Australia) the students used the Internet to search about Matter and watched a Youtube clip showing the animation of the states of matter on an interactive whiteboard. There was less digital technology used in the German cases.

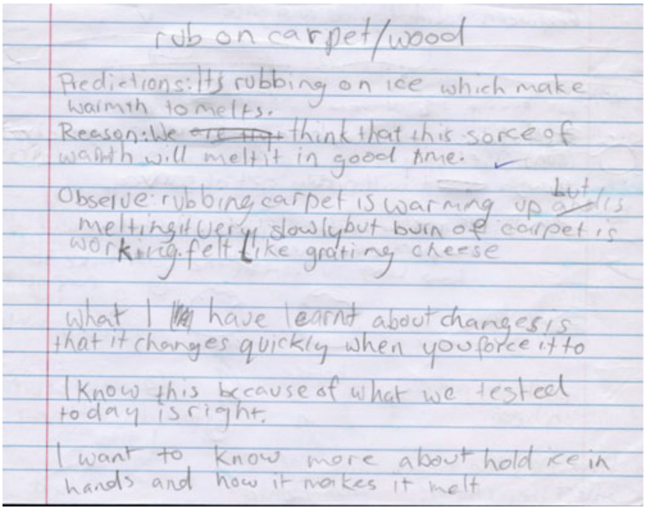

Fig. 10.1 An example of a student's learning journal from Ms Noone's class

Provision of Opportunities to Develop Inquiry Process Skills

Science inquiry skills transcend the content. In all the cases in the project there was a focus on the learner, the science content, hands-on activities and inquiry process skills, but with differing emphasis. The hands-on activities provided opportunities for the development of inquiry skills. For example, Ms Hong (Taiwan) reflected on how students often had difficulties in taking measurements when observing the moon phases. She responded by modelling the measurement of direction and azimuth in the class and having students practice in the schoolyard so they could undertake the task at home.

Experimentation was used to support meaning making, children used inquiry process skills when they made predictions, recorded results and explained their observations. For example, in Ms Lennard and Mr Arnold class as well as in Ms Petersen's class (both in Germany) the students had to design an experiment and make a model to solve the problem or to demonstrate their newly gained knowledge.

In all cases there was evidence of students developing the science inquiry skills as described in the TIMSS report (Martin et al. 2012); however, the amount of teacher intervention and support varied. This can vary according to the needs of the students, the nature of the topic or the personal teaching style of the teacher. There was variation as the extent of guidance, the amount of information that was presented and the degree of closure that was given to the students in undertaking inquiry processes. For example, Ms Hong (Taiwan) guided the students' thinking very closely and their contributions were sharply framed by the questioning which tended to ask for confirmation or interpretation within a narrow range of choices whereas Ms Lennard and Mr Arnold (Germany) deliberately neither framed children's interpretations nor confirmed directly the legitimacy of their views. Mr Roberts (Australia) did not provide immediate feedback, but asked questions to channel the students' thinking.

The Strategic Use of Dialoguing and Questioning to Direct Student Learning

In all cases active communication was promoted through a range of discursive strategies to develop explaining and reasoning skills (Chap. 6). The ratio of student to teacher talk tended to be higher in the German classes than in the Australian or, especially, the Taiwanese classes. However, the data do not reveal the depth or effectiveness of the discourse. The cases suggest that when the proportion of student to teacher talk is high, more time is allowed for students to explain their ideas and share explanation. This does not necessarily mean, however, a difference in students' experience of reasoning during the class.

The teachers used questioning extensively to keep track of students' ideas and move them forward. There were differences in the way this was done across the cases, sometimes with a whole class and other times individually. Mr Roberts encouraged the children to use scientific language as the Taiwanese teachers and Ms Petersen (Germany) did. Like the other teachers he did not pass negative judgments on the children's comments or indicate that they were correct or incorrect, but rather moved the discussion forward with affirming utterances like "We'll have to test that idea". Similarly, Ms Lennard and Mr Arnold (Germany) promoted a written discussion of ideas using the 'dancing chairs' strategy'(Chap. 5) where every single child constructed a commentary or explanation and got written feedback on his or her idea by at least two peers.

Understanding the Needs of Individual Learners

Providing for the individual needs of learners was a feature characteristic of all teachers in this project. Differentiating teaching to cater for the different needs of the learners was evident in the cases. Teachers intentionally directed questions to individual students, targeting their needs, so each student was challenged. Mr Roberts, for example, gave instructions to the whole class on making a whirlybird, and then helped students individually where needed, even modelling the instructions for some students. Teachers monitored individual student's progress as they asked questions, provided feedback and directed the discourse. In Mr Roberts' class he tracked student thinking about science ideas. For example, when he asked a student why he thought a scrunched up piece of paper would fall faster to the ground than an identical piece of flat paper, the student replied that the scrunched up one was heavier. Mr Roberts acknowledged the student's response but did not evaluate it. However, later in the lesson, after the students had explored the science concept, Mr Roberts recast the question and directed it to the same student, challenging his misconception.

Discussion

There are differences among the members of each national team concerning the perception of quality and there is no collective understanding of the nature of quality teaching. The results identify common aspects of quality teaching across the cases drawn from three countries. However, the data presented suggest that these common aspects are represented differently within different cultures. The reflections by the researchers highlight the culturally embedded nature of these teachers' practices through referring to the context, and principles underlying them. There are differences in the emphasis and interpretation of teachers' practice by the home researchers, commonly reflecting the intentions of the teachers themselves. There are obvious differences in the setting of the science classroom, such as the time devoted to teaching science each week, the amount of prescription of content and its support by officially sanctioned resources, whether the teacher is generalist, or science specialist, how the content is taught, as a stand-alone subject or integrated with other curricula, access to laboratories, the presence of digital technologies in the classroom, the assessment requirements, and the recognition of the value and importance of learning science that is communicated from the community to the school. These key aspects reflect different emphases on science education across the three countries.

Common Aspects Identified in the Cases That Are Culturally Independent and Culturally Dependent

The findings consistently show that culture has an impact on the nature of the teaching and cannot be separated from it. Country-specific curriculum traditions and norms of practice set the scene for the duration of lessons, teacher qualifications and expert knowledge in each country. In Taiwanese culture the teachers are highly respected. The curriculum is closely prescribed and the teaching is also highly structured to support students to understand the science concepts and to perform well in the common tests and achieve the standards. The curriculum regulates what is taught and the assessment regime regulates expectations of student achievement standards. For example, the end of term exams in Taiwanese classrooms provide feedback to which students, teachers and parents can respond. Germany and Australia have less standardised assessment regimes and the formative assessment is more likely to be conducted interactively during the lesson.

The resourcing of schools is usually determined by the government or school board and reflects the importance placed on accessibility to advanced technological resources to support teaching. In Taiwan, for example, the schools were very well resourced and the teachers commonly integrated learning technologies into their teaching.

While there is no national curriculum in Germany, there is a local curriculum for each German state. There is also a shared practice recommended by teachers associations and in the specialist literature that good science teaching uses the students' experiences as a starting point to clarify, experiment, compare and develop ideas to answer questions about our environment (see Chap. 2 for details). The German primary school has a focus on the holistic development of the child through a more integrated approach with science taught in context. In primary schools in all German states science is taught as part of Sachunterricht, a general subject comprising general knowledge considered of relevance to young children with elements of social studies, science, citizen education, health care etc. These priorities mean that science is often not taught as a separate subject. These cultural influences are seen in our cases, for example, with the German teachers fostering extended discourse and having a student-centred approach to learning, represented by the exploratory nature of lessons and the writing tasks that granted the children complete freedom on what to write and how to express what they have seen.

In Australian society relations are more relaxed and informal and this is reflected in the classroom. For example, students would not always stand when an elder entered the classroom whereas in Taiwan and some classes in Germany this is normal behaviour. Science is allocated less teaching time in Australia than in Germany and Taiwan. It is not a high priority to many primary school teachers and parents in Australia.

The pace of lessons has a cultural influence with the requirement in Taiwan to teach the necessary science content in a particular time frame which means the lesson must proceed at a fast pace. These constraints are not so evident in the cases of the other two countries where the teachers have comparably more freedom to decide how much time they want to spend on a special lesson unit.

The use of dialogue and questioning to direct student learning is a common tool that all the teachers used effectively but it is used differently in each country. The ways the teachers engage students to learn are common across the three countries. The cultural influences seem minimal, while a relevant context and challenge seem more important. The teachers have shown how they target aspects that will appeal to the learner.

Acknowledging children's ideas is a common aspect that is achieved in different ways. For example, in the cases from Germany there are many opportunities for students to be heard individually. In Taiwan students received immediate feedback in the whole class discussion. The emphasis on working efficiently towards a canonical concept was important in Taiwan, consistent with the assessment requirements.

This is very different to Germany and Australia where scientific knowledge was conceived of more openly with diverse student views engaged with.

Mostly the cases exhibited aspects of scientific thinking and reasoning processes which encompass the shared emphasis on inquiry skills and inquiry teaching approaches. However, the understanding of what constitutes inquiry varies across the countries. The level of inquiry depends on the control the teacher gives to the students. In Taiwan, examples of inquiry that were observed were strongly teacher led.

The coordinated use of multiple and multimodal representations was a feature of most teachers' practice; however, there was strong variation between cases. The Taiwanese teachers made greatest use of digital representations; the Australian teachers frequently used objects and talk to represent their ideas, whilst the German teachers often used objects and written and spoken accounts of the phenomena being investigated.

Conclusion and Significance

There are aspects of science teaching observed in the sample of cases that represent quality in a way that transcends culture, but there are differences between the countries that point to different perspectives on quality. The similarities and differences among the three cases are culturally framed and need to be considered in light of the habitus, tradition, current contexts, and expectations that are embedded in teaching practice for that country.

There are cultural and system circumstances that shape the conceptions of quality in the different cultural settings. We can only define quality in relation to a particular context. The core elements of quality science teaching that are identified are broadly consistent with the research literature (Mercer et al. 2009; Parker 2004; Ramseger 2013). These are:

- a commitment to engaging students,
- monitoring and acknowledging students' ideas,
- fostering science inquiry skills,
- the coordinated use of representations,
- the strategic use of questioning and dialoguing to direct students' learning, and
- understanding the needs of individual learners.

While the analysis has identified quality characteristics of the teachers' practice in each case, it demonstrates that it is not possible to generate a single definition of quality. There is variation in the ways that these common elements are manifested in different cultures and for different teachers. The core elements and the variety of ways they are expressed in different countries by science specialist and generalist teachers have significant implications for teacher education and for primary science education policy, which are discussed in detail in Chap. 12.

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Chapter 11
Reflections on Video-Based, Cross-Cultural Classroom Research Methodologies

Mark W. Hackling, Gisela Romain, and George Aranda

Rationale for the Use of Video and for Cross-Cultural Studies of Teaching and Learning

Video offers a number of powerful affordances for investigating the intricate and complex nuances of the teaching-learning interactions occurring within classrooms. These affordances have been made possible by technological advances which enable researchers to use multiple digital cameras connected to external FM microphones which offer a number of perspectives on classroom activity and a clear and rich recording of dialogue. Social and cognitive processes of co-constructing meaning are mediated by talk, embodied representations such as gesture and role play, graphical and textual representations. Video offers unique affordances to capture the multimodality of these representations and interactions (Flewitt 2006). The video recordings provide a large corpus of data and a permanent record of events that can be replayed, sampled, shared and analysed from different theoretical perspectives using a range of analytical approaches. With classroom video being captured as digital files, it is now possible to import these files into software tools that can facilitate transcription and annotation of video, and analyses involving ethnographic, open or closed coding techniques.

A significant challenge for those researching in cultures that are new to the investigators, is the capacity to notice events and interactions that are salient and to make

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valid interpretations of their meaning, in the cultural context in which they occur. Repeated viewing of video clips and the opportunity to share and discuss these with colleagues that are natives of the culture to help get below the surface features of the teaching and learning behaviours and to discern the deeper significance of events and interactions is only possible when there is a permanent and multimodal record of the lessons. The rich multimodality of video offers opportunity to identify communication styles and representational forms, and to understand their particular significance in a given cultural setting.

Multi-theoretical Perspectives

The EQUALPRIME research explored the ways in which teachers create rich opportunities for higher order thinking and reasoning in primary science classes, and the ways in which this is framed within different social and cultural settings. The wider team of researchers hold social constructivist and a broadly sociocultural view of learning which takes account of the wide range of sources and levels of culture that influence personal and shared knowledge construction which includes the culture of the community, school and classroom together with "the culture of science with its particular forms of language, reasoning and representation" (Hackling et al. 2013, p. 1). It is recognised that the various forms of representation created by both teachers and students are powerful mediators of learning and have particular meanings within a given classroom culture (Lemke 1998; Vygotsky 1978).

Within the primary science contexts of our case studies, language, material objects as well as symbolic and embodied representations all act as semiotic resources from which meaning is constructed, represented and communicated; teachers and students are immersed within a highly multimodal milieu (Kress 2010). Both material objects and other representations can also be considered tools that mediate learning within an activity system (Engestrom 2001) in which teachers and students play particular roles shaped by division of labour, rules and culture. In these settings teachers need rich pedagogical content knowledge to orchestrate a range of multimodal representations with explicit pedagogical links between them to support student meaning making (Hackling et al. 2013; Scott et al. 2011). Distributed cognition recognises that cognition in not limited to the mind of one knower but is distributed between people, across materials and objects, and time (Hutchins 2010; Nersessian 2006; Xu and Clarke 2012). This set of connected theoretical perspectives provide a rich and holistic theoretical framing to view, analyse and interpret classroom video data, but also provides particular lenses through which classroom events can be understood. Drawing on this set of complementary lenses, enabled the diverse research teams with different research agendas to create data interpretations which were meaningful to colleagues working in different settings.

Methodological Challenges of Video-Based Classroom Research

Researchers have identified a number of methodological challenges in conducting video-based cross-cultural studies of teaching Clarke et al. 2008; Hackling et al. 2014). For the EQUALPRIME study, challenges included: bridging the research cultures of the Australian, German and Taiwanese research teams; managing the complexities of ethical and privacy requirements for research; comparability of sampling and data capture across countries; data sampling for analysis; maintaining the rich multimodality of the raw data; translation of German and Taiwanese transcriptions into English; other language issues like different use of certain terms in different languages and problems with subtitling of videos; forms of analysis and data re-representation; and, most significantly, minimising cultural bias in data interpretation.

Bridging the Research Cultures of the International Research Teams

The EQUALPRIME project brought together researchers from three different countries, each with distinct research cultures, and research teams from five different universities. Each of these teams had common histories of conducting classroom research in science education; however, they each had different research priorities and agendas which were framed by different cultural, historical, contextual and theoretical perspectives. Initial meetings between some of the research team leaders and the development of the research grant proposal provided a starting point for the development of a shared understanding of the theoretical framing and research approach proposed for the project (cf. Chap. 1).

Once research grant funding had been secured, an initial meeting in Berlin of chief investigators (CIs) from all of the research teams was the point at which there was detailed negotiation of a shared repertoire that defined the research design and procedures. This included issues of sampling, ethics and data sharing protocols and how data analyses and co-authoring of papers would be conducted on a cross-cultural basis. This meeting and subsequent meetings of CIs for data sharing and analysis were critical for developing shared perspectives, a common language to talk about teaching, learning and research, and to build trust between teams and an empathy for the cultural contexts in which the cases of science teaching and learning were researched. Given the culturally framed perspectives that researchers brought to viewing teaching in other cultures, this deeper awareness of local contexts and cultures has taken many years to develop through the life of the project.

Complexities of Ethical and Privacy Legislation

Video-based classroom research poses a number of challenges including issues of time and costs of capturing quality video, conducting analyses and protecting the rights of participants. Schuck and Kearney (2006) argue that the ethical “issues of confidentiality and ownership are important and need to be thoughtfully considered by researchers before this new technology becomes ubiquitous in qualitative educational research” (p. 447). “Given the nature of digital video data, there are important ethical issues that need to be addressed relating to the identifiability of participants, and the need for fully informed consent for all potential uses and users of the video data” (Hackling 2014, p. 4). Despite these challenges many large scale and international studies are generating video case studies which provide rich descriptions of teaching and learning and we have seen the emergence of video ethnography (Fitzgerald et al. 2013) which provides rich documentation of classroom cultures and practices.

The purposes for which classroom video data can be used need to be considered carefully to fully understand the ethical implications of this type of research. Classroom video can be analysed to reveal the complexities of teaching-learning interactions in that classroom. Video data can also be shared with other research groups for cross-cultural studies of teaching and learning, used to communicate research findings and as a resource for teacher professional learning. Derry et al. (2010) explain that video can be used within a research group and then progressively to more distant and wider audiences including undergraduate teacher education, conference presentations, shared with other research groups though a controlled access archive and ultimately shared through open access on the www. Not only do these more distant audiences and users have to be very careful about selection and interpretation of samples of video taking into account to context in which the data were gathered, but this sharing of video also raises a number of ethical challenges in relation to these emergent users and uses of video research data.

For the EQUALPRIME project, an application was made through Deakin University to gain approval for a multisite research project involving all CIs from the Australian, German and Taiwanese research teams. The application was required to meet the standards and protocols required by: the *Australian Code for the Responsible Conduct of Research* (NH&MRC et al. 2007) jointly issued by the National Health and Medical Research Council, the Australian Research Council and Universities Australia; and, the National Health and Medical Research Council’s (NH&MRC 2007) *National Statement on Ethical Conduct in Human Research*. The application was required to address protocols regarding informed consent; data management, access, retention and/or disposal; and, some aspects particular to video research such as providing for students for whom consent was not given for participation in the research. In addition to gaining consent of the Australian university’s Human Research Ethics Committee, consent was also required from the Education Departments within the Australian states, school principals, teachers, parents and students.

In Taiwan privacy regulations were not as strict as in the other two countries involved, and it was therefore less difficult for the Taiwanese team to get approval for filming in the schools. This was eased by the fact that there existed strong relationships between the research team and the participating teachers, and the chief investigators were well known to the schools over a long period of time.

In Australia as well as in Germany the situation was more complex: school principals, teachers, parents and children were provided with information letters which explained the research and active written consent was obtained from each of these for participation in the research. Potential participants were informed about the research procedures and that those who did not wish to participate in the research would be seated in a video 'black spot' within the classroom so that they would not be captured on the recording. Participants were assured about data access and security and the purposes for which data would be shared with other research teams. Although participants were assured that research findings would be reported anonymously, the use of video for conference presentations and teacher professional learning would make each participant potentially identifiable. Principals and teachers retained the right to approve the use of video clips for these purposes so they could ensure that only positive images of the schools, teachers and students would be portrayed. Consent was obtained for:

- participation in all data collections which included being recorded on video, participation in interviews and provision of classroom artifacts;
- sharing of data with other research teams;
- approval of selected video clips to be shown at conferences or used for teacher professional learning; and,
- use of data for publication of research findings.

The researchers agreed to follow the principles of the Vancouver protocol developed by the International Committee of Medical Journal Editors to guide issues of authorship of publications and to ensure that any publications arising from cross-case analyses included authors from the country in which each case study was collected.

The ethics protocols established under Australian policy and guidelines were adopted by all CIs; however, the privacy laws of Germany were even stricter than those of Australia regarding the public showing of children's images. For the German cases the team needed to attend a parents' evening, give an explanation of the project to the parents and receive the written consent of all parents of students involved as well as permission by the data protection authority of the Senate of Education. Parents were asked for their consent to the sharing of video clips and images with the international partners for joint analysis. Parents also consented to video clips and images being shown at conferences. However, in view of the strict local privacy regulations permission to publish video data on the internet was not applied for and videos may only be used and presented publicly by members of the EQUALPRIME research team.

Comparability of Sampling and Data Capture

To ensure there was a basis for making comparisons between case studies collected in different cultures, a shared repertoire was negotiated as a basis of selecting comparable samples of teachers, age group of children, science topics and research data sources (see Chap. 1).

The recruitment of teachers focused on identifying experienced and effective teachers of science based on peer nomination, interviews with the teachers and initial classroom observations. Given the small number of case study teachers, no claims are made about the representativeness of the sample of teachers from each country. It was agreed that case studies would involve the teaching of science to students in the fourth grade in each country as these students were of similar age (9–10 years) and the range of science topics included in the curriculum of each country was similar. It was agreed that the research teams in each country would collect case studies focusing on the teaching of topics from each of the science disciplines; astronomy (earth science), forces (physics), materials (chemistry) and ecology (biological science). Each topic was taught in the normal way that the teacher would teach the topic consistent with local curriculum requirements; as such, these were natural case studies (Yin 2014).

Research data collections were standardised in that they were gathered over the teaching of a whole science topic which took between 5 and 17 lessons; and, the same types of data were gathered using the same methods. The primary data source was video recordings of lessons using two cameras with external FM transmitter microphones to ensure high quality recording of discourse that could be transcribed for analysis. One camera followed the teacher whilst the other filmed a focus group of students. In Germany a third camera on a tripod was used to film the whole class from an upper corner of the classroom to get an overall image of what was going on in the whole class. A standardised classroom observation form was used in all of the three countries so that an overall summary of classroom activity was compiled during the filming of each lesson (Fig. 11.1).

An initial teacher interview was used to elicit information about the teacher's beliefs, instructional intentions and the context in which teaching occurred. Brief interviews were also conducted prior to and after each lesson. Teacher interviews were also used to check data interpretations made by the researchers. Focus group interviews were conducted after most lessons to gain students' perspectives on significant events that occurred during a lesson, and occasional video-stimulated interviews were conducted to check students' intentions and actions. Where teachers conducted whole-class assessments, usually at the beginning and end of topics, students' work samples, tests or journals were collected and copied for analysis. The assessment records provided insights into students' thinking, however, they were not suitable for making claims about learning gains. Other classroom artifacts such as interactive whiteboard files complemented the other data collections. These extensive data collections provided a rich source of information from which case studies were compiled and from which cross-case analyses were conducted.

Date/Time: **Teacher:** **Lesson No.:** **Lesson Topic:**

Focus Group Composition:

From Pre-lesson Discussion with Teacher:

Teaching /Learning Purpose *("What is your plan for the lesson? What ideas and skills are you hoping to develop during the lesson?")*

Observation of Classroom Setting and Activity Sequences

Whenever there is a "turn" in the instructional setting or classroom activity, record the elapsed time, the type of activity, setting change and add any relevant comments.

Elapsed time (mins)	Instructional setting	Classroom activity	Comments

Codes			
TI	Teacher instruction	WCA	Whole class activity
WD	Whole class discussion	SGA	Small group activity
SD	Small group discussion	ISA	Individual student activity
SW	Seat work	IWB	Interactive whiteboard activity
Mat	Students sitting on the floor	NIT	Non-instructional time > 2 mins
Out	Instruction is outside the classroom		

Fig. 11.1 EQUALPRIME classroom observation form

A significant challenge for cross-cultural case study research is the extent to which findings can be generalised beyond the cases or to what extent the findings from cross-case comparisons represent comparisons between cultural settings or individual teacher differences. Yin (2012) distinguished between statistical generalisation which is typical of experimental research and "analytic generalizations (which) depend on using a study's theoretical framework to establish a logic that

Lesson	1	2	3	4	5	6	7	8
Aim								
Concepts								
Processes								

Fig. 11.2 An example of a format used for outlining a unit of work

might be applicable to other situations" (p. 18). Analytic generalisation as applied in qualitative research follows a two-step process:

> The first step involves a conceptual claim whereby investigators show how their study's findings have informed the relationships among a particular set of concepts, theoretical constructs, or sequence of events. The second step involves applying the same theoretical propositions to implicate other situations, outside the completed case study, where similar concepts, constructs, or sequences might be relevant. (p. 18)

The research design adopted for the EQUALPRIME project provides a basis for making comparisons between cases set in similar and different cultural settings. Findings emerging from these comparisons highlight the influence of the teacher's own beliefs, philosophy and unique pedagogical repertoire; and, reveal common patterns and approaches to science teaching within cultural settings.

Sampling of Data for Analysis and Issues of Representativeness

Our research which is guided by broad questions takes an inductive or whole-to-part approach (Derry et al. 2010; Erickson 2006) to analysis which begins by considering the whole body of video data to identify major events and themes, and then progressively focuses on particular events in greater detail. The emerging themes are then interpreted within the theoretical framing of the study to generate assertions about teaching, learning and culture.

Each case study generated a large corpus of data including up to 25 h of classroom video and many interviews with the teacher and the focus group students. Given the time-intensive nature of data analysis using micro-ethnographic methods or data coding using software tools such as *Studiocode or Videograph*, pragmatic decisions had to be made regarding sampling the data set for the more intensive forms of analysis. Analysis, therefore, proceeded in two phases. In the initial phases of analysis of our video case studies the research teams prepared an overview of the story line of the whole unit (see Fig. 11.2).

We have also found it useful in this initial phase of analysis to document the instructional settings employed by the teacher i.e., whole-class, small group and individual student activity, the sequence in which they are used and the time devoted to each instructional setting. By re-representing these data as a stacked column graph, broad patterns of teaching-learning activity can be identified and assertions can be developed regarding the teacher's use of instructional time (see Chap. 4).

Concurrent to the viewing of all video data from each case for the analysis of instructional settings, analytical memoing supported the documentation of reflections on the ways in which teachers were supporting higher order thinking and scientific reasoning in their lessons. As Groenewald (2008) explains:

> Memoing is the act of recording reflective notes about what the researcher (fieldworker, data coder, and/or analyst) is learning from the data. Memos accumulate as written ideas or records about concepts and their relationships. They are notes by the researcher to herself or himself about some hypothesis regarding a category or property and especially relationships between categories. These memos add to the credibility and trustworthiness of qualitative research and provide a record of the meanings derived from the data (p. 506).

The questions being investigated by the research team and the analytical memos guided the team's selection of the data to be analysed in more detail in the second phase of analysis. Some of these analyses were based on a single lesson from one case study, others involving cross-case analyses involved lessons or parts of lessons sampled from one case from each of Australia, Germany and Taiwan. Inevitably, small and possibly unrepresentative samples were selected for the most intensive forms of data analysis and the data represent aspects of the teachers' practice that were effective in supporting students' reasoning. In reporting these analyses great care is required to ensure that findings are appropriately contextualised into the broader patterns of teaching and learning so that readers can make appropriate interpretations of the research reports which are based on samples of data.

Questions of representativeness are addressed at two levels. First, the initial analysis of instructional settings which is based on all lesson videos provides insights into the teachers regular pattern of teaching, and second, the more intensive analyses of the ways in which teachers support students' reasoning, based on samples of data, can be interpreted in terms of the nature of the samples and in the broader context of the culture, school, topic and regular pattern of teaching of the teacher.

Maintaining the Rich Multimodality of Video Data Through Multimodal Transcription

The most powerful affordance of classroom video data is that it captures the rich multimodality of classroom interactions and representations. Video captures the use of language; symbolic, graphical and embodied representations; and, manipulation of objects by teachers and students. As data analyses proceed through phases of data reduction, analysis and data re-representation, researchers are challenged to maintain the rich multimodality of the raw data.

As Bezemer and Mavers (2011) explain, the rich multimodality of the video data has required the development of new methods of multimodal transcription and as yet no standard conventions have been established by which audio, visual and embodied data can be re-represented. A significant challenge for the research was therefore a capacity to construct accounts of events in ways that capture the multimodality of the data and provide a capacity to work between transcripts of discourse, and view video clips of classroom activity and images, videos and interactives utilised by the teacher on an interactive whiteboard. It became necessary to develop multimodal transcriptions that include contextual information, time stamps, transcripts of discourse, descriptions of semiotic resources such as gestures, role plays, images and manipulations of equipment, and images and short video clips embedded into the multimodal transcript (see Fig. 11.3). The digital format enabled the researchers to open digital representations of multimodal objects and processes and view them whilst reading the transcriptions of discourse and description of how gestures were being used.

This form of multimodal transcript extends the matrix style utilised by Baldry and Thibault (2006) which combined still photos with descriptions of body movements and language used, by embedding digital images and film clips that can be opened and played. The inclusion of video clips helps address the challenge of combining the use of language and other visual, spatial and temporal elements, but not the perceptual difficulties that arise when attempting a simultaneous reading (Flewitt et al. 2009).

Software Tools Used for Transcription and Coding

Studiocode (on Macintosh computers) and *Videograph* (on Windows computers) were the video coding software programs used in the EQUALPRIME project. *Studiocode* was developed in Australia (http://www.studiocodegroup.com/) and it has been used for various educational and teaching purposes. It allowed the research team to quantify teaching and learning behaviours within lessons. For example, differences in the amount of time teachers were talking compared to how long students were talking and how these varied between teachers was investigated. In Chap. 6, teacher discursive moves are reported based on analyses using *Studiocode*. How teachers interacted with students in ways that promoted their reasoning was investigated by coding the duration and frequency different types of discursive moves.

Inqscribe was one of the transcription programs used (http://www.inqscribe.com). It allowed classroom discourse and interviews to be transcribed from either video or audio files. The transcription could be time-locked to the data, which meant that transcriptions and translations could be synched with the video footage and subtitled, so that the transcripts could be viewed within the context of the lesson video. This was particularly valuable to support data sharing between the research groups.

TIME (mins)	CLASSROOM SETTING	SPEAKER	UTTERANCE	OTHER SEMIOTIC RESOURCES	VIDEO CLIP
Episode 4 Teacher uses a diagram of Australia and a satellite image (static and spinning) of the Earth on the Interactive Whiteboard (IWB) to represent, *how night and day are caused by the Earth spinning on its axis.* Explaining the concepts: *the Earth rotates on its axis once a day causing day and night, the sun rises in the east and sets in the west.*					
11:13	Whole class: students sitting on the floor facing the IWB.	T	If I go to the next page, what's happening here? What can you tell me about this picture?	IWB Slide 31 **shows** a satellite **image** of the Earth. Half of the Earth is in darkness and the other half is in the light.	
		S	That half of the Earth is dark time and the other half is light time.	S points to the dark side and then light side of the Earth on IWB Slide 31.	
11:30		T	So this half of the Earth is still dark and this half of the Earth is light...and look at Australia. What is the difference between Sydney and Perth?	IWB Slide 31 T **points** to the west coast of Australia which is in darkness and then to east coast which is in light.	
11:44		S	Perth is in dark time and Sydney is in the light.		
		T	Sydney is in light and Perth is still in the dark time. So which part of Australia sees day time first, Perth or Sydney?	T **points** to Sydney on IWB Slide 31 and then points to Perth.	
		S	Sydney		
12:05		T	Sydney gets the sun first. I would like you to think what is the Earth actually doing? The earth is doing something. The sun would be here providing all of the light on this side of the globe. What's the Earth doing?	Ss **view animation** of the Earth spinning on its axis. IWB Slide 31 T **positions her body** on the right hand side of the screen with her arms extended towards the IWB to **show where the position** of the Sun would be in relation to the movie.	Rotating Earth day & night - PlanetObserv
13:00		S	Spinning		

Fig. 11.3 A sample from a multimodal transcript

Videos with English subtitles helped research groups to view video footage from other countries, as the cultural nuances and non-verbal cues such as gesture and eye-contact could be lost in transcriptions alone.

Complexities of Language Translation

In view of the increase in international, comparative and cross-cultural research in education involving several languages, language related methodological issues still receive only minor attention. This may in part be due to the fact that there is no simple solution to questions concerning translations. While certain words may not exist at all in other languages, even words which appear easily translatable carry meanings which may differ considerably within and across languages. Crossing language barriers (Temple and Young 2008) inevitably results in a loss of meaning. Yet, we would like to argue that cross-language research not only involves loss but can also lead to gains in terms of insight when used in a reflected way.

As outlined earlier, the research team comprised researchers from all three countries from which case studies were collected. However, no member of the research team was familiar with all three languages involved. Language issues played an important role and concerned all phases of the research project from the research design phase through data collection and preparation, analysis and interpretation up to presentation of research results.

Given that the meaning of such terms as scientific reasoning, inquiry teaching and quality teaching are highly contested even among members of the same linguistic community, different interpretations among members from different countries with differing local research traditions would be expected. The team thus spent some time on negotiating the meaning of key terms of the research project before approaching more practical issues. These discussions proved fruitful not only in terms of the research design but also for understanding context factors in the countries involved and were picked up again in meetings throughout the research process. Once the team had found working definitions for key terms of the study, methodological aspects were agreed upon in a shared repertoire, which also included aspects of data transcription and translation (see Chap. 1).

In view of the amount of data that was to be collected it was decided that not all data were to be translated. Rather, each local team undertook a preliminary analysis of the data collected and then chose a certain number of scenes according to jointly agreed upon criteria which were then transcribed and translated into English which was the working language of the international team. Additional scenes were sometimes translated at a later stage, if these appeared of interest for a particular analysis.

In large scale research projects such as TIMSS or PISA, back translations (Brislin 1970) of translated material into the original language are often recommended in order to ensure reliability (Squires 2009). This may be useful for the development of questionnaires for quantitative research. However, back-translating requires several professional translators and accordingly considerable financial resources. Alternatively, translations are undertaken by one of the team members and then discussed and checked with other members of the team (Squires 2009).

In the case of EQUALPRIME, professional translators were used for translation of the Taiwanese data, while the German data was translated by a team member of the German team. Finding professional translators to translate classroom talk is not an easy task. Translators must not only be highly proficient in both languages (Squires 2009), but also familiar with children's talk and the specific vocabulary of science classrooms in a given culture. While context knowledge proved to be an advantage for finding adequate translations, translation undertaken by a research team member may also tend to be more biased towards a certain interpretation (Temple and Young 2008).

Transcribing and translating talk from a primary classroom is particularly challenging not only with regard to specific terminology used, but also in terms of rendering an adequate translation of unfinished sentences, wrong order syntax and other particularities (Ramseger and Romain in press). For example, a child struggling to find the correct words to express a new thought may make several attempts by starting a new sentence, stuttering, combining different nouns to create new words, which do not exist. Such instances may be significant to the researcher but prove very difficult to translate. In such cases, where additional information on connotations of a particular word was deemed important by the translator, footnotes were used to limit subtleties lost in translation.

The representation of oral speech in written language is in itself a transformation that is not unproblematic. As Lemke writes: "The process of transcription creates a new text whose relations to the original data are problematic. What is preserved? What is lost? What is changed? Just the change of medium from speech to writing alters our expectations and perceptions of language. What sounds perfectly sensible and coherent can look in transcription confused and disorganized." (Lemke 2012, p. 1472). For translators as well as the researchers working with translated data viewing the original video data rather than relying on transcripts proved essential not only for understanding the language but also in terms of such aspects as context, pitch of voice and other non-verbal aspects. The team agreed to use *Inscribe* for transcriptions, so that translated transcriptions could easily be turned into subtitles of video clips to be used for analysis. However, the usefulness of subtitles is limited by the fact that each caption should not exceed a certain amount of signs for the viewer to be able to read them while simultaneously watching the video. This often means that sentences in the subtitles are shortened, which in turn may alter meanings and interpretations.

In view of all the above mentioned limitations, the team's ground rule whereby all interpretations must be cross-checked with and authorised by the team which collected the data becomes particularly important. Most analysis involved joint analyses by members from different countries at some stage. Beyond the translation of data, language also plays a role in the development of coding. As Stigler et al. (2000) have pointed out; joint video viewing may be useful for finding codes in cross-cultural settings. While the crossing of language barriers in cross-cultural research needs to be carefully considered, cross-checking interpretations with local team members may help overcome some of the limitations and may also open new insights into words and meanings in different contexts (cf. Chap. 13).

Noticing Salient Events

Once episodes had been selected and multimodal transcripts developed to document the episodes, the Edith Cowan University research team met to view the video clips, work with the transcriptions and collectively conduct an analysis of an episode using a collaborative form of ethnographic microanalysis (Erickson 2006). The team of researchers repeatedly viewed a video sequence, reviewed multimodal transcripts, identified significant actions, processes, representations and links between them and documented them through analytical memoing. Given the researchers' different theoretical and pedagogical commitments, initially, each researcher typically focused on a particular aspect of the teaching and learning exemplified by the video data. For example, one researcher would see aspects of discourse being highly significant to making sense of the teaching-learning process while another researcher would identify embodied representations as being significant. Researchers would 'notice' an aspect of pedagogy as being salient and then interpret and reason through the meaning and significance of that which had been noticed.

With repeated viewing of the video clip and careful scrutiny of other evidence, consensus between researchers emerged as to the themes and relationships in the data and how the effectiveness of the teaching and learning practices could be best explained. By triangulating and aggregating the perspectives afforded by the professional vision (Sherin and van Es 2009) of the different researchers, much richer documentation and analysis of practice emerged, and it is likely that more credible data interpretations made than would be possible from an analysis conducted by a single researcher.

Data Re-representation

Following sampling, data reduction and analysis, data were re-represented to reveal the patterns and relationships within the data. The forms of re-representation utilised were related to the forms of analysis, the characteristics of the data and the purpose of the research. The patterns of instructional settings used through lessons and throughout a topic were represented as stacked bar graphs as exemplified in Fig. 11.4. Further examples of data representations are presented below. These relate to analyses of classroom discourse.

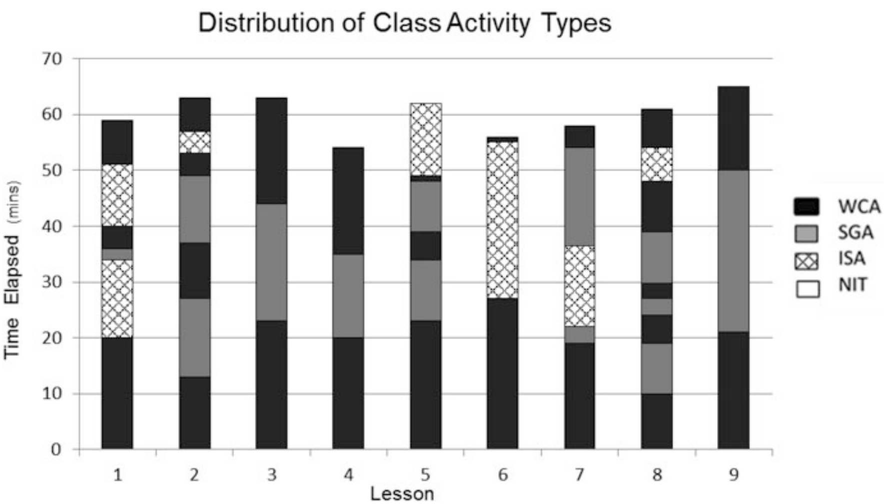

Fig. 11.4 Distribution of various instructional settings throughout the nine lessons of a primary science topic. (*ISA* individual student activities, *SGA* small group activities, *WCA* whole class activities, *NIT* non-instructional time)

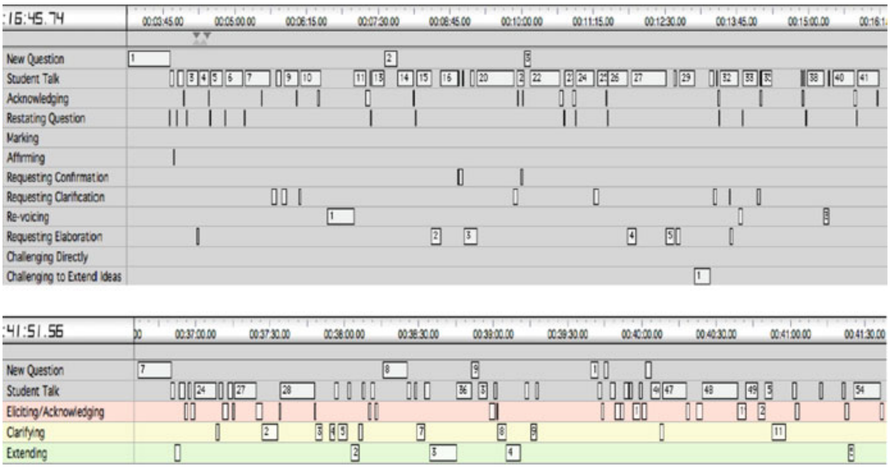

Fig. 11.5 (**a**, **b**) Linear representations of discourse moves coded using *Studiocode* software

Linear Representations from Studiocode Analyses

The following figures represent the output of *Studiocode* analyses in a linear form. Both figures refer to coding of teacher-student discourse (discussed in greater detail within Chap. 6). Figure 11.5a shows the analysis of teacher discourse moves which were coded according to how the discourse move was interpreted as facilitating student reasoning. Figure 11.5b shows the collapsing of these individual codes into

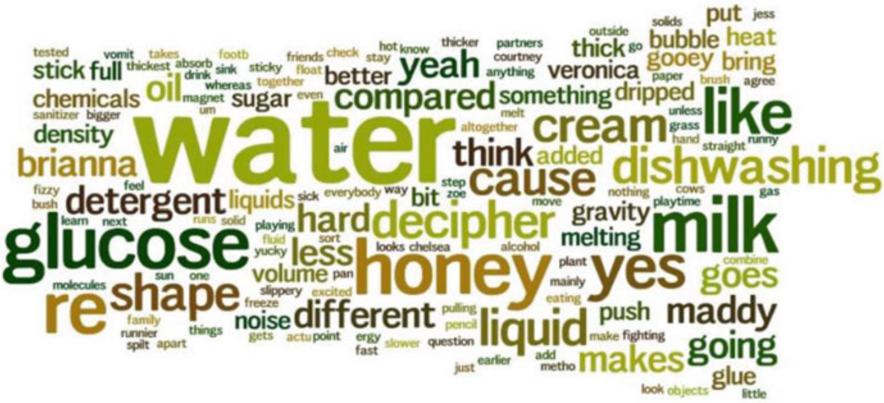

Fig. 11.6 The frequency of student word use in a science lesson

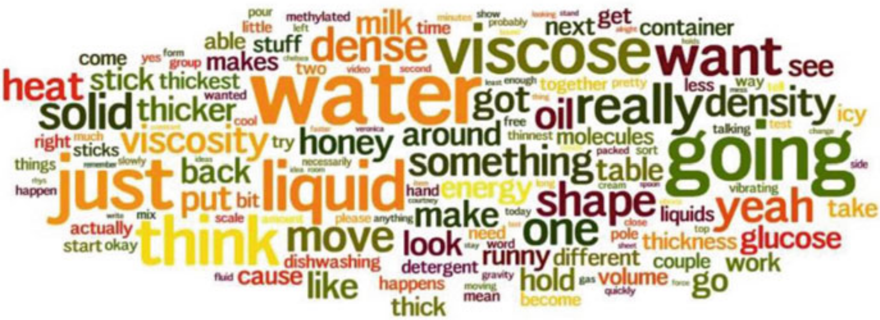

Fig. 11.7 The relative frequency of teacher word use in a science lesson

larger categories. These linear forms of data representation capture the temporal nature of the evolving patterns of teacher talk and provide a capacity to aggregate codes into more general categories in a transparent way that can be audited.

Wordles Representing Teacher and Student Talk

Wordles are representations of word frequency analysis conducted on sample of text (http://www.wordle.net/). In our research, wordles have been used to represent the relative frequency that different words have been used by the teacher and by her/his students in a single lesson. Figure 11.6 is a representation of the frequency of words used by students in a lesson on the viscosity of liquids, larger words indicate the more frequent use of the words, and Fig. 11.7 is a representation of the teacher discourse in the same lesson.

A comparison of teacher and student wordles reveals the extent to which scientific vocabulary introduced by the teacher is picked-up and used by the students. In this example it is interesting to note that the scientific terms liquid, molecules and density which were introduced by the teacher have been utilised by the students in their talk. These analyses have found to be useful in pre-service teacher education.

Limiting Cultural Bias in Data Interpretation

Given the interpretivist epistemological stance of the EQUALPRIME researchers, it was recognised that each researcher's cultural and professional history, and theoretical and philosophical commitments would strongly influence the interpretations made of classroom events and that this may lead to invalid interpretations of events in classrooms from other cultures. Strategies were adopted to minimise the risks of cultural biases resulting in inappropriate data interpretations (cf. Chap. 13). These strategies included visits to classrooms to observe teaching in all three participating countries and regular meetings of all researchers to monitor progress, share and analyse data, and to present findings as joint symposia at international conferences.

Classroom Visits

Classroom visits were organised by the host-country and allowed the visiting teams to observe teachers conducting science lessons with Year 4 students. Going to the classrooms allowed the visiting team members the chance to observe lessons *in situ*, observing the student-teacher and student-student interactions, the classroom environment and broader characteristics of the schools. Host members were on hand to answer any questions that arose during the teaching of the lessons, which allowed for contextualising of the observations, as to whether they were unique to the teacher, school or the region. These classroom visits were often followed by the opportunity to talk to the teachers, the students and school leaders. These conversations allowed the teacher to answer questions about their practice and explain where in the curriculum this lesson was situated and any particular educational philosophy that had influenced the teacher's practice.

These visits were conducted throughout the project and added in different ways to data collection and interpretation. At the beginning of the project they allowed the visiting members to draw their own conclusions and inferences about the classroom lessons they observed in each country, before they had observed the video-data of the EQUALPRIME case study teachers. These visits also allowed the host-country researchers to see how differently their own classrooms were being observed from an outside perspective, with visiting-members having their own notions and preconceptions about each other's practice. Later in the project, after the team members had made classroom visits and had observed hours of video-footage from each culture, there were extensive discussions about cultural differences within the EQUALPRIME team. The classroom visits, analyses of video and discussions within the research team enabled the researchers to gain deeper insights and richer understandings of the cultural and contextual factors influencing teaching in the three countries.

A variety of primary schools were visited in each country which gave some indication of how teaching practices were influenced by the educational philosophy of the schools and the impact of local contextual factors. For example in Taiwan, metropolitan schools and a school for indigenous students were visited, which provided insights into the variation of settings and practices within that country.

Research Group Meetings

An important part of the EQUALPRIME project was planned meetings amongst the team in each of the team countries as well as other countries to coincide with international science education conferences and symposia. These included meetings in Denver, Vancouver, Gothenburg, Cyprus, Adelaide, Melbourne, Sydney, Perth, Taipei, Munich, Spitzingsee and Berlin. Individual members of the team spent time in each other's faculties for extended analysis and writing.

Planning

In the planning stages of the EQUALPRIME project and just after its commencement, members of the project convened to discuss how the project would proceed. This included the development and refinement of the shared repertoire, discussion about protocols of how video-data would be shared, issues related to differences in the requirements of ethics in different countries, translation of transcripts into English, and planning meetings that could coincide with international conferences.

Team Progress

Frequent meetings allowed for teams to report their progress. This involved discussing the progress of each team, with their recruitment of case study teachers, impediments that each team had been experiencing and their future plans. As the project progressed, the meetings focused on issues that related to outcomes of the projects such as analyses that were being turned into publications and resources for preservice teaching.

Analyses

Individual teams conducted some analyses on their own cases according to their theoretical interests whilst cross-cultural analyses involved researchers from each of the involved cultures. Regular meetings allowed for analyses to be shared between the international teams. Each team presented their analyses, which may have involved their own national and other international case study teachers. This encouraged discussion about the interpretations each team was making about the other nation's case studies in an informal setting. This informality allowed for a broad discussion about particular ideas that eventuated from the analyses and misapprehensions that could be discussed. Consistent cultural themes across cases could be highlighted and their underlying reasons could be unpacked. This allowed for subsequent analyses to take into account the relevance of these cultural themes.

Some of the issues discussed at these meetings included: the extent to which the practices observed in a relatively small number of case studies could be generalised to the practice of each country, the influence of different curricula, parent expectations and extra-curricular study on student achievement.

Conference Symposia

At each of the conferences and symposia, data were presented, either as presentations by individual country members or as a collective. These presentations allowed for the dissemination of results in a formal environment, both for people who were in the audience and to members of the EQUALPRIME project. It also allowed for the opportunity for the results and analyses to be presented to case study teachers in the audience, and allowed audience members to question them about the video-data and contextual information. Critical friends were invited to be discussants at these symposia so that independent critiques of the research could be considered by the teams.

Conversations occurred before these presentations, in order to clarify any cultural issues about the data being presented (e.g. the Melbourne team presenting about a Taiwanese teacher from a particular theoretical perspective asking "was this analysis consistent with a Taiwanese point of view?" or the Taiwanese team's understanding of the teacher's video-data).

Methodological Advancements of This Study

With any multi-team and cross-cultural research project, the major challenges are to establish a common research culture and approach across the teams and to minimise inappropriate data interpretations due to cultural biases. The negotiation of the shared repertoire was critical for bridging the research cultures of the Australian, German and Taiwanese research teams and to establish a common basis for conducting the research in all three countries. This common approach to research with its agreed sampling and data collection protocols ensured that valid comparisons could be made between cases, recognising however, that generalisation beyond the limited samples of teacher in each country would not be appropriate.

The negotiation of the shared repertoire, classroom visits, regular research team meetings and joint presentations at symposia were critical to developing a trusting relationship between the research teams, open communication and critical questioning of data interpretations made by those within and from outside a culture helped minimise inappropriate data interpretations arising from cultural biases. The inclusion of researchers from all three cultures in cross-cultural data analyses combined 'insider' and 'outsider' perspectives to enhance the validity of data interpretations. The experience of this project has revealed that developing sensitivity and empathy towards the social and cultural settings of schooling in other cultures, and an understanding of how local cultural factors impact on teaching and learning takes an extended period of time and is dependent on opportunities to visit classrooms and have honest and open conversations with local educators and researchers. As anticipated, the experience of being questioned by researchers from outside of one's own culture has sharpened our own perceptions of teaching and learning in our home countries.

The EQUALPRIME study has also grappled with the methodological challenges of analysing a large corpus of video data, adopting appropriate approaches to data analysis consistent with the theoretical framing and purpose of the study, and maintaining the rich multimodality of data through transcription, analysis and data re-representation. A pragmatic approach was taken to the analysis of the large body of video data. The first phase of analysis considered all of the teacher camera video recordings to document the use of instructional settings, what science ideas and processes were being developed through the lessons and to record first impressions of strategies used by teachers to support reasoning as analytical memos. These initial analyses helped researchers identify samples of lesson video that would provide valuable insights into teaching practices and should be subject to intensive forms of analysis. The approach to the second phase of analysis varied between research teams depending on their theoretical orientation and research interests. Two methods emerged within the research groups; micro-ethnographic analysis and coding. Both approaches were strongly qualitative, however, those who adopted methods including coding tended to use a mixed methods approach where coding supporting more qualitative approaches to data analysis and interpretation. Qualitative and case study methods with cross-case analyses are well suited to cross-cultural studies of teaching and learning where the focus is on the identification and characterisation of teaching strategies that are effective in supporting higher order thinking and reasoning and the development of students' scientific literacy.

Frederick Erickson's (2006) approach to micro-ethnographic analysis of video has been extended in the EQUALPRIME study to a form of collaborative analysis. The literature on professional vision (e.g., Sherin and van Es 2009) clearly indicates that what is noticed in a video by a researcher is strongly influenced by experience, philosophical and pedagogical commitments. Working collaboratively as a team of researchers jointly viewing video opened up a wider range of perspectives on the practices of the teachers which ultimately would be expected to lead to more credible and trustworthy interpretations of events. Open coding of data is a core method within qualitative research (Strauss and Corbin 1998) and the use of software tools to support coding is becoming widespread in video-based forms of classroom research. *Studiocode* and *Videograph* were utilised for coding teacher behaviours as it supported approaches to open coding and the establishment of a set of codes that could then be applied to compare teacher behaviours across cases. The software output showing a linear array of coded behaviours linked to time stamping from the video showing temporal progression through the lesson was also a valuable form of data representation for reporting research findings.

Two approaches were adopted for maintaining the rich multimodality of the video data through analysis and re-representation of the reduced and analysed data. First, new approaches were developed for multimodal transcription that embedded digital files of video clips and digital curriculum resources used by teachers into a conventional transcript. This created a data analysis workbench which held multimodal data that could be opened and viewed in the context of a timeline, transcripts of discourse and descriptions of semiotic resources available to students. This supported researchers to read the intertextuality of the multimodal milieu of the classroom and the pedagogical linkages made by teachers in connecting and interlinking the range of resources so that they were accessible and meaningful to students. However, as Flewitt et al. (2009, p. 45) note, transcripts are "reduced versions of observed reality, where some details are prioritised and others are left out" which means that transcripts represent only a sample of the data. Sampling remains one of the most significant limitations of this type of research.

The challenges of sampling within cross-cultural video-based classroom research arise at two levels; first the selection of cases, and then the selection of data from each case that will be subjected to intensive analysis. The small number of cases that are drawn from each country and culture can never be representative of that culture; however, they can provide insights into how the local cultural and contextual factors impact on teaching within that culture. Assertions about cultural framing of practice need to be set within the context of the cases studied and not generalised beyond them. Data sampling is subtle and yet is a highly significant limitation of this type of research. As previously noted the act of transcription is a form of data sampling as not everything is transcribed because this is part of the process of data reduction. Given the extensive set of video recordings for each case only a fraction can be subjected to intensive forms of analysis due to resource constraints. Critical to the credibility of the research is the processes of selecting samples and reporting claims made on the basis of those data samples. The choice of samples need to be made objectively and carefully justified and claims need to be reported within the contexts of the samples and the wider data set from which they were drawn so that appropriate interpretations of research can be made by readers of the reports.

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Part IV
Implications

Part IV comprises two chapters which draw on all the earlier chapters to identify implications arising form the research project; implications for practice and teacher education, and for conductiong cross-cultural comparative studies of teaching and learning.

Chapter 12
Implications for Practice and Teacher Education

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Introduction

In any cross-country comparative research one must be careful in drawing conclusions or even appropriate comparisons without being aware of the meaning of practices as seen from the particular country perspective. This point has been made in a number of the Chapters, particularly Chaps. 9, 10, and 11, and will be made again, in further detail, in Chap. 13 on implications for cross-cultural comparisons. The corollary of this is that in drawing out implications for practice in the three countries, or more generally, we need to be aware of the cultural setting of any practice that we are recommending be considered or acknowledged in other countries. Cross-country 'practice borrowing' needs to proceed carefully.

The question of whether, and what we can learn from looking across different countries' practices hinges on the extent to which teachers and curriculums from the countries are following different or similar purposes and agendas. In this globalised age in which convergence of curriculum intentions around the globe is increasing, one would expect a considerable degree of commonality in these classrooms and in teachers' perceptions of their role. For instance, a comparative study of 26 countries' STEM policy and practice (Freema et al. 2015) found an increasing emphasis on reasoning and twenty-first century skills across the globe, and common concerns and approaches with respect to STEM education, despite significantly different social and economic settings. The comparative intent of international assessments

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such as PISA and TIMSS presume a certain stability of curriculum setting, and represent a globalising agenda through which countries can learn from the conditions identified as correlated with higher performing jurisdictions.

International comparative research such as the *Learners' Perspective Study in Mathematics* (Clark et al. 2007) has identified significant differences in the curriculum practices and discursive rules operating in classrooms in different countries (Xu and Clarke 2013). Yet the intent of these studies is to learn from such comparisons, not necessarily about what practices can be fruitfully borrowed, but at least how one's own practice can benefit by the comparative light thrown on it (Stigler and Hiebert 1998).

The reaction of teachers in the EQUALPRIME project, on viewing video from other countries' classes, has also provided insights into the universality on the one hand, and cultural specificity on the other, of pedagogical choices that are made. In some cases teachers were impatient with aspects of the practice they were viewing; too much teacher guidance for some, too slow a pace of idea development for others, or at times confusion about what was going on with some teacher-student interactions. Yet in many cases the teachers could recognise the nature of the choices that were being made and appreciate these as good practice, and for some, it was clearly educative to reflect on the implications of other different practices, for their own practice.

In all these comparative discussions and analyses of the cases, described in previous Chapters, there were many significant differences to play with. These are in some cases objectively documented differences such as the different types of rooms for science education used in the cases (Chap. 3), balances of time spent in small group and whole class discussion as described in Chap. 4, or time taken in conceptual talk by teachers vs. students, as described in Chap. 6. Other significant differences relate to the degree to which a prescribed curriculum is followed, the reliance or otherwise on packaged resources, the pace of content coverage, the extent and nature of teacher scaffolding, and the different approaches to inquiry. However, such differences apply across teachers within a particular country, in many respects as much as they apply across countries. Allied to this, it is argued, for instance in Chaps. 6 and 10, that there are a number of commonalities that apply to all these teachers' practice that arguably make these cases stand out from primary teachers' practice in science more generally. In this Chapter we will consider the proposition that there are some principles of practice that apply across these three countries that have significant implications for the possibility of articulating a universal practice for science teaching in primary school. On the other hand we will explore the nature of the differences we find across countries, that we can reasonably associate with cultural traditions within the countries. Finally we will explore the implications of the study and its findings for deeper consideration of our own practices, and in particular how the cases we have developed, and insights we have gained, can inform teachers, and teacher education practices.

The Roles of the Teacher and Students in Classroom Discourse

Differences between teachers in the three countries concerning teaching and learning approaches have been discussed in the various analyses in this book. A key dimension underlying these differences is the balance between whether ideas are introduced into the public space of the classroom by the students, compared to the teacher. While there is considerable variation between teachers within countries in this respect, we argue that on balance, there is a continuum stretching from the Taiwanese cases, where the teachers in this study tend to strongly frame the ideas that are discussed in the classroom and introduce the canonical concepts directly, through Australia where we can find variation in this respect amongst our eight teachers, to the German cases and especially the case study on forces where the activities are designed to encourage students' input and sharing of ideas and the two teachers play a subtle and supportive role in guiding the discussion towards scientific understandings.

A caveat needs to be placed on this finding: that these cases cannot be taken to formally represent whole-country practices. We are talking here of a continuum across these particular cases. This issue of generalisability has been discussed in previous Chapters and will be discussed in more detail in Chap. 13. Nevertheless, the claim that these cases are representative in an important sense of some key cultural features of the countries' practice is supported by the discussion in Chap. 2 of the system features that frame these teachers' practice, such as the tightly constrained curriculum and resource provision in Taiwan, and a tradition of commitment to theoretical disciplinary concepts, contrasted with the strong German commitment to the development of the whole child through collaborative communicative processes, expressed through the Bildung philosophy.

The question of teacher and student input and control of ideas in classroom discursive practices has a number of subsidiary dimensions, which have been analysed and discussed in the Chapters of this book. These relate to the nature of teacher knowledge, the interpretation of inquiry processes and the appropriate focus on reasoning, traditions of discursive interactions, the nature of curriculum support resources and representational artefacts, and the time teachers spend on learning and planning science. Each of these will be discussed in turn.

First, there is a growing tradition in Taiwan of primary science being taught by specialist teachers in the school such that, much more than in Germany or Australia, they become much more expert in the disciplinary knowledge of the subject and able to strongly frame the learning around canonical content. In Ms Hong's case this was further supported by the fact that she taught in a school that had a specialist science program with a particular focus on astronomy, and access both to secondary teachers with strong disciplinary knowledge and sophisticated resources beyond that found with their comprehensive textbooks. This specialist tradition is both an expression of, and supports a strong disciplinary commitment in Taiwan, distinct from the broader commitments of the teachers in the German and the Australian cases. In the German case study on forces for instance the teachers were explicit in their valuing of collaborative inquiry and communicative skills more so than efficiently arriving at ‘correct’ scientific vocabulary. In two of the Australian cases both Mr Roberts and Mr Collins worked as specialist teachers even though they did not have formal science qualifications. Mr Roberts had a strong commitment to student exploration and interest and a lesser focus on resolved canonical knowledge, and Mr Collins was new to the role and learning the science as he prepared for the unit. Thus, more explicit control of input of ideas into the classroom can be seen as both a choice, and an outcome of the different cultural circumstances in relation to teacher disciplinary knowledge in the three countries.

Second, and related to this, the curriculum in Taiwan is more strongly framed around content than in Australia or Germany, with schools having less flexibility to modify or interpret topic sequences. This strong content focus is supported by a more comprehensive testing system, and by a system of approved textbooks and resources that again emphasise canonical content compared to the more flexible framing of sequences characterising the two German cases. In Australia as in Germany, the Victorian teachers Mr Roberts, Mr Collins and Ms Noon generated their own unit designs and resource supports from a variety of sources. Ms Grace was different, utilising the *Primary Connections* materials, which led to a coherent conceptual sequence supported by high-level representational resources. In the Australian cases however there seemed more time pressure on content coverage and consequently more explicit teacher input of science ideas, than was the case for the two German classes.

We conclude, however, that the balance of effects from curriculum specifications and testing meant that efficiency in introducing and negotiating canonical science knowledge was more of a requirement, and emphasis, in Taiwan. This appeared in the pace of content, the degree of explicit teacher direction in conceptual input into classroom talk, and in the access to and use of carefully prepared resources to support the learning of canonical content.

Third, the classroom focus is different in the three countries concerning the extent to which student reasoning is expressed through talk, compared to the need to be inducted into the discursive reasoning tools of science. In the English speaking science education literature there has been a long standing argument that deeper level learning is achieved through encouraging quality classroom talk, in which students reason using evidence and support their explanations through high level exchanges (Barnes and Todd 1977; Edwards and Mercer 1987; Lemke 1990; Mortimer and Scott 2003; Alexander 2006). Learning to reason in science is presumed to involve support of explicit reasoning in the classroom. In Taiwan by contrast it appears that extended talk is not valued as much in classrooms and reasoning is presumed to be demonstrated by students’ ability to respond appropriately to targeted teacher questions and challenging tasks. Ms Paulin for instance focused her attention on establishing the explicit language of the lever principle, and later challenged students to use these ideas to solve high-level lever problems without a requirement to explore these ideas through talk.

As argued above and in Chap. 6, these distinctions concerning the extent to which student extended talk is valued, appears in the percentage of time devoted to student compared to teacher talk. Similar analyses of classroom discourse have been conducted in Asian mathematics classrooms, with findings that support this analysis (Xu and Clarke 2013).

The distinction between dialogic and authoritative discourse also captures these differences in emphasis on teacher and student input of ideas. In both Mr Collins' and Mr Roberts' cases there are distinct dialogic and authoritative episodes as students' ideas are explored without judgment, then shaped through a variety of discursive moves towards canonical science concepts. In the German case on levers the talk is mostly dialogic in feel, as students express their ideas freely, but the teachers gently and consistently guide students towards productive views by inviting clarification and extension of ideas students bring into the public arena. In neither Taiwanese case, however, was there an extended example of dialogic talk. Student talk was tightly framed through structured teacher questioning.

Alongside the distinction between teacher and student input of ideas in whole class discussion, there is a distinction in the way tasks are conceived of and organised between the three countries, and the extent of valuing of group discussions in problem solving tasks. In the German case on forces, tasks were set up to prompt students to generate ideas in journals, which were then shared through the 'dancing chairs' activity (see Chap. 5) and gathered together by the teacher to focus the whole class discussion. In the German astronomy class the teacher offered activities that were helpful to find answers to the students' questions about the relation of Sun, Earth and Moon, but she started it all with asking the students about their hypotheses on the phenomenon in question. Similarly, Ms Grace's group modelling of day-night in Australia was quite open and left room for extended talk as students reported, compared to the more structured group tasks of Ms Hong and Ms Paulin in Taiwan which were devised to establish sharply conceived canonical ideas. Similarly, in Australia Mr Roberts and Mr Collins' practical tasks were generally very open and devised to trigger a variety of student ideas, which were then negotiated in the whole class discussions that followed.

Variation of Practice Within Countries

In the section above we have used the cases to argue that there are significant differences in practice that are tied to culture and context in these three countries. It is also true that there is variation within each of these countries such that on some measures teachers from different countries are more alike than teachers within a country. For instance, if we look at Fig. 4.1 (Chap. 4) concerning the balance of time spent on whole class, group and individual instructional settings, Taiwanese Case 3 is more similar to the German cases than to the three other Taiwanese cases, and the Australian cases vary considerably such that each has characteristics in common with the other countries' cases. Similarly, the discursive moves patterns in Table 6.2 (Chap. 6) show complex comparisons within and across the six cases analysed.

As pointed out in Chap. 6, many of these differences can be accounted for by teacher beliefs and classroom practice styles. Mr Roberts has a strong belief in student exploration of ideas through experimentation, and his whole class discussions place emphasis on eliciting and acknowledging student ideas. Mr Collins has a strong literacy focus which extends to his much stronger use of the Internet and the interactive white board, and student written production. He also believes in challenging students to argue for and justify their ideas, as becomes evident in his patterns of questioning. Ms Hong teaches in an astronomy-focused school, and her exploration of causal models for the moon phases extends beyond the Taiwanese curriculum which specifies only a description of moon phase patterns and their relevance for human activity. The teachers in the German case on forces follow a dialogic learning model (Gallin 2010), which is strongly principled around student exploration of phenomena and gentle teacher guidance, and this gave quite a different structure to the lesson sequence compared to Ms Peterson's astronomy unit.

Curriculum Priorities

The variation both within, and across countries reflects a variety of different curriculum priorities, with differences partly reflecting cultural histories and expectations, and partly individual teacher philosophies and beliefs. These curriculum priorities can be taken in one sense as the focused commitment to worthwhile, but varied, learning outcomes. Together they could be taken as the mapping of an inclusive set of curriculum emphases. These include:

1. Efficient promotion of science content knowledge and the ability to use this knowledge for problem solving (particularly emphasised in Taiwanese cases)
2. Student reasoning and argumentation to justify ideas (particularly emphasised in German and Australian cases)
3. Student capacity to communicate and exchange ideas (German cases as well as Mr Collins in Victoria)
4. Student collaborative processes in group work (differently conceived of in the three countries)
5. Open investigation skills (particularly in the Australian and German cases)
6. Accuracy in experimental investigation (particularly in the Taiwanese cases)
7. Appreciation of values and social interactions associated with science (especially in the Taiwanese cases)
8. Democratic expression and valuing of others' ideas (in the Australian and German cases)
9. Identification of students' capacity to perform at a high level (particularly Taiwanese emphasis)

We would not argue that these priorities are contradictory, or act against each other in a curriculum sense, except that with the pressure of time in the curriculum, and of assessment priorities, choices need to be made as to where to put the emphasis. This emphasis is strongly framed in broad terms by traditions and system processes in the three countries, but also by individual teachers' beliefs and preferences, and local school contexts.

Implications of Commonalities in Practice

In Chap. 10, we have outlined six common broad aspects of quality teaching that have been identified from the analyses of all the cases. These were: a strong commitment to engaging students, monitoring and acknowledging students' ideas; the fostering of science inquiry skills; the thoughtful coordination of multiple representations; the strategic use of questioning and dialoguing to direct students' learning; and, a profound understanding of the needs of learners. One important insight of this project was the recognition that all teachers involved in this study appeared especially qualified to represent quality, regardless of the different ways in which they actually made use of these personal resources. They did not simply follow an established path of traditional teaching, but demonstrated a clear commitment to a coherent and high level conceptual program. These teachers had all thought about the key concepts and ways of teaching them.

It is worth remarking that the teachers in all our case studies made use of their different teaching materials with great sovereignty. In some cases they had constructed or adjusted the material to suit the needs of the learning group (Chap. 7). Further, what occurred in these classrooms relates authentically to the practices of the scientific community. With reference to Moje (2007), we had pointed out in Chap. 7, that representations and their coordinated use can be understood as the discursive tools constituting a scientific disciplinary literacy into which these students are being inducted. It is the model and the process of model building that represents best the nature of the natural sciences. Constructing a model of the sun-earth-and-moon-system in a primary classroom or reproducing the constellation of the celestial bodies with the human bodies of the students or trying to reconstruct a big lever used at a building site by a small representation at the edge of a school table (Fig. 3.7 in Chap. 3) is actually the same intellectual process that occurs in real laboratories when researchers work to derive a formula, a principle or, in the end, a law of nature from observing behaviour and events. Galileo's famous saying that science is to "count what is countable, measure what is measurable, and what is not measurable, make measurable" begins in the primary classroom when children at the age of 10–12 years try to find a pattern in the table with the lengths of the lever arm and the load arm compared to the loads and the forces they have measured on the model (Fig. 12.1).

We also witnessed high level skills in managing whole class discussions that involved extended sequences of reasoning around key ideas. Although the time given to the children for answering questions or discussing utterances of their classmates differed considerably between the teachers, all our teachers took every single student utterance seriously, considered it carefully and returned the thought to the

Fig. 12.1 Detecting the principle of the lever at the blackboard by comparing load and load arm with force and lever arm (The *text* translates to: The shorter the lever arm, the more force [is needed]. The more load, the longer is the lever arm [needed]. The longer the load arm, the more force [is needed]. The shorter the load arm, the less force [is needed])

class, so that the other students could investigate, assess and process the hypotheses, claims or ideas. Thus being taken seriously by the teachers, the children responded seriously, developed and pursued high level argumentation, as illustrated by many transcripts in this book.

Reviewing all the cases we have seen, and the set of aspects of quality established in Chap. 10, we would argue that despite there being no straightforward way of articulating an operational description of quality, the characteristics of these cases, including the set of curriculum priorities as well as the six aspects of quality teaching, have strong messages for teacher practice across all three countries, and potentially globally. Thus the cases as a set provide strong messages for science education concerning, first, a set of principles of practice that should guide teachers, and secondly that should be an appropriate focus in building teacher capabilities and beliefs about practice.

However in conceiving of a quality practice in science education it is obvious that there are many choices to be made concerning curriculum priorities, and student learning outcomes.

As for the aspects within which we carved out obvious differences, while these are to an extent culturally framed, they nevertheless provide ways forward for all countries in conceiving of the different ways of approaching science education, which can inform the field of science teaching across boundaries even though particularities may not readily translate. For example the Taiwanese focus on disciplinary knowledge can resonate with all countries, as can the serious attention to group work in Australia and the focus on the whole child and prolonged sustained communication in Germany. So the different approaches to teaching and learning in the different case studies do not mark inherent contradictions; they rather show alternatives of pedagogical and didactic acting that may be appropriated in the other countries as well.

These experiences and reflections might inspire the scientific community to speculate on the possibility of a set of broad principles that could inform 'ideal' practices of science education in all countries, drawn from strengths seen in the different countries and teachers. As a reaction to the discussions in the EQUALPRIME team, a first attempt of this kind was offered by Ramseger (2013). Ramseger published a list of ten quality criteria for the process structure of quality science lessons. These criteria (see the list in the Appendix) are based on a secondary analysis of 61 publications about science teaching starting with Rousseau, John Dewey and other classic educational thinkers up to the latest empirical research from science classrooms in Europe and the Anglo-Saxon literature. This list purports to offer a description of 'the state of the art' in quality science teaching. It does not yet include all the insights we have described above. Nevertheless, it would be worthwhile to further explore whether such a set of universal principles of quality science education could be agreed upon, and what culturally-specific aspects would need to be added to such a set of common principles.

Implications for Teacher Education

The video ethnographic approach utilised in EQUALPRIME, involving complete teaching and learning sequences, provided multiple insights into the profession of teaching science from the perspective of different theoretical lenses. This research has implications for teacher education both at the in-service and pre-service teaching levels.

The effective teaching of science at the primary level should be seen as a complex set of actions which might fruitfully be interpreted from different perspectives such as, for example, the manner in which a teacher coordinates multiple representations in developing an understanding of a scientific phenomenon or the teacher student discourse that takes place as students develop their ideas within an inquiry environment. Video case studies of teaching sequences in the EQUALPRIME project have provided a valuable resource for pre-service teacher training and in-service teacher professional development.

The use of cases of actual classroom practice for pre-service teacher training has traditionally been produced in print form as descriptive documents, often presented in a narrative form. The use of video cases in pre-service teacher training represents an innovative and effective way for the pre-service teachers to observe, analyse, and evaluate teaching situations (Blomberg et al. 2013; Kurz and Batarelo 2010; Marsh et al. 2010; Wang and Hartley 2003). Kurz and Batarelo (2010) point out that when video cases are viewed by an entire class there is a shared observational experience of common cases to draw upon when discussing pedagogical practices. By capturing the complexity of the classroom context video cases provide pre-service teachers with an efficient mechanism to expose them to the authenticity of the classroom.

A useful feature of video technology, particularly digital forms, is the ability of the viewer to re-view, enlarge, or slow down what has been captured. This feature is available not only to the teacher educator for classroom purposes but may also be viewed by pre-service teachers on their personal computers at any time. It offers pre-service teachers the opportunity to view multiple perspectives of the classroom environment and in doing so demonstrates to them how a variety of simultaneous events affect teachers' instructional decisions (Kurz et al. 2004). Such insights may not be gained by pre-service teachers whilst undertaking their practicum experiences either as an observer within an actual classroom or acting in the role of classroom teacher. Video viewing is generally quite motivating for pre-service teachers (Blomberg et al. 2013) as it offers them a window into teaching without the pressure of having to interact in classroom situations (Sherin 2014).

Video cases enable pre-service teachers to make the link between theoretical perspectives that are introduced and discussed at the university and the practicum experiences in school situations. However, what is observed in videos of classroom practice by the pre-service teacher may not be as self-evident as it might be for the teacher educator or experienced teacher and so "teacher educators should, at least initially, scaffold pre-service teachers' learning from video cases, to highlight important aspects of teaching practices depicted in the cases, and then move toward open-ended activities" (Yadaz 2008, p. 36). Teacher educators can direct pre-service teachers to specific portions of a video-taped lesson to allow them to reflect on the lesson from multiple points of view (Blomberg et al. 2013). Videos can, for example, develop pre-service teachers' skills in identifying children's behaviors and learning problems or get insights into how teachers interact with children and deal with issues as they arise (Kurz and Batarelo 2010).

Apart from scaffolding pre-service teachers learning processes in the analysis and critique of video of classroom interactions Kurz and Batarelo (2010)) point out that a video case by itself may not be enough and needs to be supported by supplementary materials. Such material might take many forms, such as details about where the lesson fits within a lesson sequence, the curriculum, examples of students' work, teacher's lesson plan and/or description of his/her intentions for the lesson including reflective comments. As mentioned in several Chapters in this book, when interpreting video of classroom interactions from different countries supplementary information that includes information about the cultural educational practices in which the classroom is located is important.

The EQUALPRIME researchers are themselves teacher educators who teach pre-service and in-service teachers at the undergraduate and postgraduate levels. At the undergraduate level video cases of some of the EQUALPRIME cases have already been produced and incorporated into current pre-service teaching courses. For example, the Australian Deakin researchers used the classroom video of three classes of Mr Roberts, who taught the topic of forces, to produce cloud-based resources located within the University's online learning management system. These resources are accessible to on-campus and off-campus students enrolled in the science pedagogy unit that is part of the primary teaching course. One such resource focuses on explicating to students how an inquiry approach, specifically the 5Es inquiry model (Bybee et al. 2006), might be enacted in a classroom. The video of a lesson on air resistance undertaken by Mr Roberts was repackaged into short clips illustrating each of three stages of the 5Es inquiry model, namely, the engage, explore and explain stages. Each clip was introduced by one of the Deakin researchers informing students about what they were to view. The following narrative provided by the Deakin researcher introduces the resource.

This video focuses on one teacher, Mr Roberts, who probed children's understandings, identified their understandings, and dealt with alternative conceptions. The topic is Forces and in this video the concept of air resistance is explored. This video will draw your attention to the ways in which Mr Roberts interacted with the children; the manner in which he elicited their prior knowledge and how he set up an inquiry activity to resolve alternative conceptions that some students had about air resistance and falling sheets of paper.

There are three stages to the lesson:

ENGAGE STAGE: Exploration and clarification of prior knowledge
EXPLORE STAGE: Inquiry activity for children to explore their ideas
EXPLAIN STAGE: Explanations to findings from the inquiry activity are discussed

You will interrogate each stage in this lesson in terms of the actions taken by Bob to elicit and resolve the prior views expressed by the children.

After each clip the Deakin researcher then invites the viewer to re-view the clip and answer a particular question. For example, following the first clip that illustrated the 'engage' stage the Deakin researcher provides the following narrative:

The dialogue shows how the teacher is fuelling the discussion with requests for clarification of the ideas that are expressed. This is intensive work that is exhausting – with all children required to justify and reason. The dialogue is led by the teacher. He is in control of the direction he wants it to take in terms of fostering children's ideas about forces and air resistance.

How does Mr Roberts deal with the alternative conceptions expressed by the children? Watch this excerpt again.

In a similar vein, online pre-service teacher learning packages have been constructed, using selected EQUALPRIME video excerpts, on discursive moves, inquiry teaching structures, and planning investigations.

The Taiwanese researchers in their role as teacher educators are more flexible in the use of video captured in the EQUALPRIME project. Videos of Taiwanese cases within the EQUALPRIME project have been used to illustrate effective practice of science teaching within different themes for pre-service teachers and also used as stimulating media to help the pre-service teacher to reflect on teaching practices concerning instructional management and the teaching and learning of scientific inquiry. The researchers also show video clips from other countries and the students discuss what they have seen and learned from viewing the video. The students are also asked to discuss what aspects of the video they have seen might be applied to the Taiwanese context. Through such activities the pre-service teachers gain insights into various ways in which inquiry-based teaching might be implemented whilst at the same time considering the affordances and constraints on aspects of this teaching which are linked to local contexts.

The German researchers in their role as teacher educators also used videos captured in the EQUALPRIME project. Students have been shown video clips and asked to describe and interpret what they saw in the classrooms. One clip showing an Australian teacher discussing the states of matter was found by the German pre-service teachers "astonishing" with respect to the high intellectual level of the lesson. One comment from a student after watching the beginning of a Taiwanese lesson was, "It seems to be very effective teaching and the feeling of being part of a group of students seems to be fostered when all students can answer at the same time, sometimes shouting out loud what they think is the answer." A video clip showing the e.future-classroom in Taipei (see Chap. 3) gave the pre-service students insights into how interactive whiteboards (IWB) can be used effectively. In Germany there is an ongoing discussion, on whether and in what ways IWBs can offer added-value for teaching and learning. So watching videos from science classes in other countries widened the horizons of the students and gave cause for rethinking the practices they commonly experience in their home countries.

The advances in digital technology have led to higher quality videos and at the same time greater accessibility of videos of classrooms to be used as media for professional learning of practicing teachers not only at the personal level but also within groups. Video can support collaborative learning of teachers in the context of a shared common experience (Borko et al. 2008) within a community that might be called a video club (Sherin and Han 2004). A video club consists of a group of teachers who meet to watch and discuss excerpts of videotapes of their teaching. Whilst videos might be used in multiple ways such as highlighting exemplary practice or exploring dilemmas that teachers encounter in their classroom, Borko et al. (2008) point out that for video clips to be effective tools for teacher learning, they must be viewed with a clear purpose in mind.

The Taiwanese researchers also use video capture of classrooms to support the professional learning of in-service teachers and their graduate students who have video recorded their own lessons in order to research their own practice, as well as to reflect on the teaching culture of Taiwan by comparing it with the teaching practices in other countries. These researchers hold monthly meetings that have a focus on research but also on improving practice. Researchers, higher degree students and practicing teachers are invited to a forum where teachers share videos of classroom practice with the rest of the group in order to analyse and discuss various aspects of the lesson thus providing feedback to the teachers who have provided the video.

Apart from the video other supplementary material is considered. For example, one higher degree student who was researching the application of the 5Es inquiry model (Hackling et al. 2007) in her practice also provided pre- and post-tests and lesson plans to be discussed alongside the video. The monthly meetings might also have themes arising from the analysis undertaken from the EQUALPRIME project. For example: a discussion about how classroom dialogue was analysed in an EQUALPRIME project case (Chap. 7). The videos may give the teachers insights into, for example, dialogic and authoritative discourse in action so they gain a more profound understanding of how the theoretical approach may be applied in practice.

Thus, the EQUALPRIME cases provided insights into teaching and learning strategies used in different schools and countries. Some strategies have proven to have universal value. For example, the ‘dancing chairs’ strategy observed in one of the German cases has now been seen as an effective means to develop children’s literacy skills. The dancing chairs strategy (see Chap. 5) can be seen as a written feedback from peers used to explore pre-conceptions and support children’s development of more scientifically adequate conceptions (Freitag-Amtmann et al. 2016).

The results of the project also raise the question whether teachers who will be teaching science in primary schools should be trained in at least one field of science, as is often the case in Taiwan. In Germany as in Australia most teachers in primary schools are generalists, who at best may have elected some science courses during their teacher training at university, but who were generally trained to teach a wide range of topics in primary school. It should be remarked that all teachers trained as generalists in our case studies shared a strong personal interest in science. After all, this was one of the criteria by which they were chosen for this study. And of course they prepared the units which were recorded by video with particular care.

These teachers differ profoundly from many of their generalist colleagues in that they are not afraid to teach science. Quite the contrary can be said of many teachers not only in Germany and Australia, but also in Taiwan. Hackling et al. (2007) have described a chain reaction starting with low pedagogical content knowledge in the sciences which generates teachers’ low confidence and self-efficacy, and as a result, these teachers spend only limited amounts of their teaching time on teaching science, which in turn leads to fewer opportunities for students to learn science with resulting low student achievement in science.

However, as the Taiwanese cases show, this chain reaction can be interrupted if teachers are adequately trained to teach science and are provided with sufficient opportunities to improve their teaching practice by taking part in professional development groups.

All this may lead us to question whether science specialists should be preferred to generalist teachers for science teaching in primary schools. We know that mere hands-on activities cannot be seen as a sufficient method for science teaching. The children need systematic structured guidance by a teacher with strong content knowledge in science. Sustainable knowledge will only be gained through the discussion of personal activities and experiences in structured dialogue in situations of sustained shared thinking (Minner et al. 2010; Ramseger 2013). Yet inexperienced and under-confident teachers can put misplaced trust in hands-on activities alone, as sufficient in themselves for promoting learning.

The COACTIV Study (2003–2007) of the Max-Planck-Institute for Human Relations in Berlin examined the relations between content knowledge and pedagogical content knowledge of mathematics teachers. The COACTIV researcher stated:

> Our data show that specific aspects of teacher competence are systematically related to differences in instructional quality. Pedagogical content knowledge predicts students’ cognitive activation in the classroom. The more a teacher knows about how instructional content can be made accessible to students, the more challenging the students perceive their

> instruction to be. None of the other facets of teacher knowledge made a unique contribution to explaining the level of cognitive activation. (Max-Planck-Institute 2009, Main Findings, para. 7)

There is no reason to assume that these findings which concern mathematics teachers do not apply to science teachers.

The deep grasp of content and subsequent conceptual depth of teaching sequences in our Taiwanese cases, the teachers' dedication to science, and their access to quality professional learning opportunities, raises questions about the nature of preparation of teachers for teaching science in Australia and Germany, and the level of support for teachers to subsequently specialise in and take part in serious professional learning in science. On the other hand, the sophistication of the teachers' creation of rich classroom exchanges in our German and Australian cases, and their construction of inquiry sequences that engaged students in independent but structured inquiry tasks, has potential implications for professional learning practices in Taiwan.

But perhaps the deeper message for science teacher educators and their students is not so much in the possibility of borrowing ideas for classroom processes, but in the expansion of possibilities to look at their local practices from a broader perspective. As with the EQUALPRIME team, participating in the experience and analysis of other cultures' practices and contexts can be a significant educative experience that throws light and feeds back into new insights concerning what is possible or desirable, in our own practices.

Appendix: Ten Quality Criteria for Science Teaching

1. Make nature question-able
Good science teaching takes as its starting point a natural phenomenon that provokes the children's sense of wonder. Together with the children, the teacher formulates a question about this phenomenon in such a way that they can find a meaningful answer to it
2. Build on the children's existing knowledge
Good science teaching begins by identifying and discussing children's preconceptions of the phenomenon in question. It confronts their ideas with new questions, observations, and (experimental) experiences
3. Involve the children in the construction of experimental designs
Good science teaching seeks, where possible, to involve the children in the construction of an experimental design that will yield an answer to their question. If the children are not yet capable of such involvement, and the teacher must therefore give them a predefined experiment, they must at least be aware – or must develop an awareness during the lesson – of the question about nature that the experiment is supposed to answer
4. Practise working in a meticulous way
Good science teaching encourages children to take a close look at things, to document their experiences carefully, and to distinguish between questions, assumptions, assertions, and observations

(continued)

5. Foster scientific discourse
Good science teaching fosters orderly discourse among the children about their assumptions, observations, and findings. From this perspective, it is a form of language teaching
6. Use models and representations
Good science teaching develops suitable graphics, models, and representations with the children
7. Take the socio-historical context into account
Good science teaching broadens the children's view of the phenomenon in question by giving them an insight into its historical, cultural, and social significance
8. Show that scientific knowledge is subject to change
Good science teaching shows the children that our answers to questions about nature are always tentative and that science is always a work in progress
9. Secure learning gains
Good science teaching enhances the children's competence
10. Facilitate experiences that boost self-efficacy
Good science teaching enables the children to find an answer to a question about nature by means of independent reasoning, thereby strengthening their sense of self-efficacy

Ramseger (2013, 161). Online: http://tinyurl.com/ramseger-qualitaetskriterien

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Chapter 13
Implications for Cross-Cultural Comparative Studies of Teaching and Learning

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Comparative Studies of Classroom Teaching and Learning

Knowledge of science and the process of reasoning are arguably some of the more frequently compared topics in comparative studies of education. They are believed by many, such as the Russian pioneer of comparative education, Konstantin Ushinsky, to be less governed by the tradition and characteristics of different cultures (Hans 1962). Most of these studies involved policy and document analysis or interviews on teacher perspectives (Bereday 1964; Swain et al. 1999), and more recently, with data from large-scale international surveys (Atkin and Black 1997; Beaton and Robitaille 1999). Nonetheless, in the buoyant expansion of comparative education research, relatively little has been done on the comparison of classroom activities in the manner and depth of EQUALPRIME. This may partly be due to the complexity and difficulties of such studies (even beyond what would be expected in the more document-based comparative studies), and partly because it does not seem to generate as much interest when compared to the more popular and mainstream large-scale comparisons of learning achievement or policy comparison.

Over the past decade the use of videotaping has been popular for cross-cultural comparative studies of classroom practices. It is believed that teaching is a cultural activity and cross-national achievement differences are quite possibly tied to cultural variations in teaching. Many scholars advocate that cross-cultural comparison, through classroom video studies, is a powerful way to unveil unnoticed but ubiquitous practices, to reexamine the taken-for-granted notions of teaching and learning, and to suggest new approaches that never evolved in a society (Stigler et al. 2000).

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Robin Alexander, in his well-known book *Culture and Pedagogy* (Alexander 2001), compared the system and practice of primary education in five countries using video records. The study included both Numeracy and Literacy lessons as examples and compared lesson structure, classroom organisation and activities, judgment in teaching, interaction patterns and learning discourse. In his reflection, he clearly pointed out the need to trace the contemporary characteristics of the system and practice back to their cultural and contextual roots in order to make sense of some of their defining characteristics.

The TIMSS study by Kinney (1997–1998) showed video clips of American, Japanese and German teachers teaching the same topic. The images of an eighth grade Japanese mathematics teaching were eyes-widening to policy makers and the public in the US because of how seemingly ineffective the practice was in the US. Also, Baker and Le Tendre (2005) used TIMSS data to compare teaching among countries in search of the quality of a 'universal math teacher'. They believed teachers in these nations faced similar problems and used the same solutions in the contemporary public school system and that there is a global model of teaching that has expanded around the world with the influence that globalisation has brought to schooling. Even though there are also national and regional forces that affect teachers' working lives, they recognised that core instructional behaviours are more likely to vary within nations than between nations.

Of all the approaches to cross-cultural comparative research, video studies indeed have the greatest potential to inform classroom practice. They can help with not only capturing teachers' lesson patterns that reflect teachers' culturally-based scripts for teaching but also with recognising learners' perspectives in classroom teaching and learning process (e.g., Stigler and Hiebert 1999). As Clarke (2004) points out, the learner's perspective approach toward lesson sequence analysis may offer an informative complement to the survey-style video studies and have the potential to address: consistency of lesson structure over lesson sequences; degree of variation in lesson structure in the practices of competent teachers; the extent to which the variation is linked to the teacher's instructional intentions, and to the actions of the students; as well as student awareness of the structure of the lesson and how it is related to the consequent nature of their participation in the lesson, and to their subsequent learning. However, based on his long-term involvement in international comparative classroom research, Clarke (2013) reminds us that making generalisations about national patterns of classroom practice can be at the cost of explanatory power if researchers do not understand the particular cultural conditions underpinning the practice. It is important to be aware that the research intent behind "the pursuit of commensurability" in cross-cultural comparative studies sometimes can result in misrepresenting valued performances, school knowledge, and classroom practice. Clarke suggests that "Acts of cross-cultural comparison must start from shared understandings of the limits to prescision in the application of any construct beyond its authoring culture" (p. 17).

The EQUALPRIME study does not fall into the current mainstream international interest in large-scale comparative studies of educational achievement. It is a theoretically rigorous comparative study at micro-level and a research-oriented, cross-cultural and collaborative project. Although sharing similarities in methods and findings with some of the above studies, EQUALPRIME possesses a number of unique features. This last chapter shares the experiences and lessons learnt from this video ethnography study that could contribute to better handling of future cross-cultural collaborative studies. It focuses particularly on methodological issues relating to pedagogical concerns, contextual exploration and cultural understanding in cross-cultural comparative studies.

General Methodological Issues

In terms of the difficulties of doing comparative studies, there are some pragmatic and practical concepts of the problems encountered by the researchers working within the field of comparative education. Many of these dilemmas relate to fundamental methodological and implementation problems faced by all educational and social science researchers, but here, based on our EQUALPRIME experience, we focused primarily on issues related to a cross-cultural comparative study.

Comparing Across Countries and Cases

What is often expected from cross-national studies involving two or more countries are generalisations about the national units, and an analysis of the commonalities and differences among them. The issue of comparison and generalisation has proven problematic throughout this study and was a challenge at all stages of the research process. Although this is defined as a comparative study, it has not been the aim to compare or rank but to learn by looking at each other's practices. As a matter of fact, direct comparison in the hope to achieve generalisation across countries is not really possible for practices that are so culturally framed. On the other hand, even exploring the differences within one country, could be a comparative study in its own right. But the focus of this study is on quality teaching in science education. It is about recognising that quality can be presented in many different forms, and trying to identify the aspects of quality, rather than to compare which is the best.

As Crossly and Watson have pointed out (2003), one of the most frequently acknowledged problems in comparative and international research is that of bias. We are all conditioned by our personal background and experiences in the interpretation and analysis of cases. It is not always easy to leave out or to recognise the inclusion of these influences on our judgments and comparisons, let alone overcome them. However, for researchers involved in cross-cultural or cross-national studies, it is particularly essential to be aware of potential biases and assumptions. Mostly the research team kept true to this tenet but it required a continuous and conscious effort, which was possible mainly because of the duration of a close collaboration between the teams. Most of the assumed findings from direct comparisons were only eliminated at the later stage of the discussion process.

Sampling and Representativeness

Selection of cases was a significant challenge at a number of levels even though efforts were made to establish an understanding on case selection from the start. The teachers and classrooms in the study were selected based on recommendations from respected leaders in science education. The classrooms chosen represented local examples of 'good teaching' (strong, passionate and quality primary science teachers) as defined by the local research teams and/or local teaching community. They may not have always represented common teaching practices but rather teaching practices that deviated positively (in the eyes of the local research team) from mainstream teaching in each country or area. It is clear that they may have represented more the idealised notions of teaching of the local research teams than about what actually happens in the average classroom.

To reduce and select data for the purpose of making comparisons across countries was also a difficult task. The video clips shared among the international research teams were pre-selected by the national research team. At a macro level, the small number of cases in the sample from each culture could not be considered representative of teaching and learning within a culture. At a micro level, the small samples of lessons from each case, analysed in detail to reveal strategies that supported higher order thinking, could not be considered representative of a teacher's practice. However, through the comparisons, we were able to identify similarities and differences of teaching and learning across countries, and most importantly, we were able to recognise some idiosyncratic and locally invisible features of teacher's practice within our own country.

As it has been reflected in Chap. 11, data sampling is subtle and yet is a highly significant limitation of our EQUALPRIME study. It was clear from the start that these samples were unlikely to be the 'norm' in each context. At most, they represented a recognised good teaching practice in the given context, but the representativeness could only come through the local research team articulating where this practice sat in relation to the more general practice. This notion had to be challenged and probed as part of the data triangulation process. In the interpretation of the data and assertions drawn, caution was used to take into account the macro level and micro level sampling issues.

The Use of Video-Taping

Case study approaches are known for having the advantage of aiming to explain what is happening rather than what is supposed or anticipated to be happening. Video recording was very important in achieving this purpose of the study. In analysing videos we are very cautious about the possible challenging dilemmas in cross-cultural comparison, such as the use of culturally-specific categories for coding; the use of inclusive categories to maximise applicability across culture; the use culturally-specific criteria for cross-cultural evaluation of teaching quality; and, confusion between form and function which been identified by Clarke (2013). In watching a number of teacher videos, one begins to understand what aspects of the local system culture transcend individual practice; which is further enhanced during classroom observation. It not only helped to capture the instructional events in classrooms for analysis in greater depth, but also served as a stimulating medium for reflective dialogues. These would not be easily achievable without examining the footage.

Nevertheless, sharing the clips alone would not have been sufficient; the role of the researchers responsible for the videos is vital in helping to interpret what is going on in them. Without this interpretation, it is almost impossible to be objective enough about what is in the video, even when one is viewing an example from one's own context. The opportunities of having both 'cultural insider' and 'cultural outsider' examining the video clips together not only enhanced the data interpretation in context, but also helped researchers to see the practices in new perspectives. The interrogation of sections of video with a team of researchers enabled critical incidents to be used to define and illustrate reasoning. The analysis and interpretation really come from a combination of the video clips and the interpretive discussions shared by the researchers.

Language Matters

> For the purposes of true communication and research, equally important is a second, positive function; a knowledge of language lets one in on the intimate secrets of the nation under study. (Bereday 1964, p. 139)

Language skill for cross-cultural researchers is important. Few researchers can realistically expect to be fluent in more than one or two languages, but it is vital, at the very least, to recognise the implications of language and language complexity both in examining data and in research collaboration. Even with experienced researchers on international studies working in each team, language has been a stumbling block in the study, not only in the translation of data but also in the collaboration of the study. The dominating use of English naturally made the distribution of some of the research work unbalanced. The translation of Mandarin and German into English has not only been time-consuming but also difficult. To have a better understanding of classrooms in different cultures requires translations that can capture the contextualised and socially framed meanings in the dialogue. Quite often when there was not enough background knowledge of the original language and context, the researchers from different countries could hardly ‘read between the lines’ in the translated language. It was particularly difficult when the focus was on the reasoning process. Despite efforts being made, some meanings were inevitably lost through the process of translation and the pursuits of linguistic equivalence are often not sufficient enough to guard against validity threats. Moreover, the challenge of language also lies in the communication and understanding between the research groups and in joint writing. The dominance of English in the international academic atmosphere is not always fair for non-native speakers and is unavoidably an imposition and restriction to some of the researchers. As Peña (2007) reminds, in addition to linguisitic equivalence, functional equivalence, and cultural equivalence are factors that need to be considered when reserch repertoires, data and findings are translated to other languages.

Collaboration Between Cultures

There are many advocates for working in more depth, alongside local researchers with knowledge of their own context (Crossley 2000; Crossley and Watson 2003) in cross-cultural research. At the same time, the inclusion of one’s own country in a comparative study raises technical questions as to the weight of data inclusion. The familiarity of the context can make judgements about data inclusion simplified or overly-trivial. The possibility of these problems was guarded against by closely collaborating with the other research teams during the analysis. Although each team played a more critical role in the analysis of their own examples, all were also heavily involved in reflecting on and analysing the cases of others. The in-depth sharing of data, experiences and contextual background helped the teams to reflect on their own inclusion of data. Different perspectives were evident amongst the researchers but over time a shared understanding or interpretation of the data emerged.

The regular and close working relationship between the international research teams was in itself a challenge and a learning process. In the process we learned not only the cultures underpinning the cases we examined, but also the work ethics across the countries in order to work collaboratively and openly in the analysis of cases. The challenges of working across cultures at times had to do with the way systems were organised. For example, there were difficulties with the way information could be shared due to ethical and privacy constraints and different expectations about how research could be conducted in each system. At times it could also be uncertainty about foreign values and manners. Quite often the researchers would have had an established relationship with the sampled teachers from their country and other researchers may have had a more reserved attitude with courtesy when commenting on the videos or observations during the face-to-face meetings. It could also be difficult to know the real opinion of the local researcher as to the status of the teacher and teaching being observed; there are certain niceties that are observed with respect to the quality of teaching, that leave some uncertainty about the local status of the teaching approach.

In terms of the more conceptual issues, concepts are not universal (Khoi 1992; Grant 2000) and there are necessarily differences in how each country conceives of education and learning, which could be difficult to understand. As Clarke (2004) points out, the researchers' cultural affiliations inevitably contribute to the form of their analysis. In other words, cultural presumption is common and can often direct how we analyse examples from other cultures. In sharing and examining the classroom data, there were cultural expectations that were then broadened through the discussions and understanding of the socio-cultural and socio-political situations of the context. Many factors impinged on the way classrooms operate in particular contexts and it was extremely difficult to fully understand their purposes and constraints in a short time. At times the overwhelming 'exoticness' of a foreign culture might lead to prejudice and misinterpretation in the analysis. For all of us, cross-cultural ethnographic study is a learning process, regardless of how familiar one is with the contexts, and it requires an openness to new insights at all times.

Cultural differences are also reflected in the relationship between the researchers and their targeted samples. The different power dynamics between the researchers and their classroom teachers was also an uncontrolled variable in the whole study. This was partly cultural and partly because of the system. In this study, the teachers were also involved in the research in very different ways in different countries: from being actively involved in the analysis, as in Taiwan; to being involved in teaching or doing research at the same university, as in Australia; or to being former students or having taken part in a school development project evaluated previously by members of the research team, as in the German case studies. These factors may have influenced the particular preferences of individual leaders of the research teams to include the cases resulting in the sampled cases not being representative of national research cultures.

Essential Pedagogical Concerns

In terms of conducting comparative studies on classroom teaching and learning, there are challenges in capturing the quality and understanding the meaning of pedagogical practices cross-culturally. Particularly, many challenges are related to the appropriateness of frameworks for analysis and supporting arguments for interpretation. As Clarke (2013) points out, in seeking to make comparison between the practices of classrooms situated in different cultures, the drive for metrics along which the comparison can be made is problematic. Based on our EQUALPRIME experience, to avoid making superficial generalisations of national patterns of pedagogical practice, we believe it is essential to explore three key driving forces behind pedagogical practices in the different countries: teacher beliefs, contextual factors and cultural attributes. By looking into the hidden forces, it indeed helps us making better sense of the pedagogical practices in different countries and increasing deeper understanding of the essence of quality teaching in different cultural contexts.

Unfolding Embedded Beliefs

It is very important to understand the teacher's philosophy as to the effective teaching of science and his/her pedagogical intent and reflections on the lessons that were captured. Teachers' pedagogical practices often reflect their own experience, the system and social expectation. The primary data selection and analyses have been conducted by researchers on data of the home country with little involvement of other country teams, largely because of the difficulties in finding a fair and common lens for cross analysis at this stage. Each culture values some unique styles of teaching and has different expectations of the teachers and learning outcomes, so it took a considerable amount of time for all the teams to understand and come to terms with what analyses were needed. While working closely together on agreed aspects of the analysis, at times shared interests on new topics developed, and at times differences in analysis foci and research interests emerged between the teams as the study developed. This is often a reflection of the researchers' own research interests as well as features of teaching and learning valued in their own context.

While information gleaned from the classroom videos was the central data source, the opportunity to interview the teachers about their ideas and philosophies was invaluable. It was clear that there would be benefits for the teachers and the quality of the research from involving the teachers more in analyses. In this study, the teacher interview data collected before, during and after the lesson sequences has given us additional insights to teachers' voices. This part of the teacher data helped us to interpret the practices by providing insights into the teachers' ideas and instructional intentions and validating data interpretations. Similarly, the stimulus-recall student interviews provided insights into their perspectives of how various teaching approaches supported them in learning science.

The chance to work with the teachers and acquire their input on our analysis of their work and to gain student perspectives provided opportunities for data triangulation and added greater insight into teaching and learning captured by the case studies.

Exploring Contextual Factors

As many of the researchers in the field of comparative and international education had already come to realise in the early twentieth century, cross-cultural studies require a thorough understanding of the external system that shapes and influences teacher ideologies and practices (Crossley and Watson 2003). The variation within education systems combined with the variation between countries and cultures added to the difficulty of making generalisations.

School visits are common in educational research, but still we have been surprised by how much extra one learns by visiting schools. The videos could be very much a circumscribed view into the world of a particular teacher. Going into the classrooms within and outside of one's own country brought the data alive and provided a lot of additional contextual information to the video, as did meeting the teachers and talking with them. The school visits enabled us to fully see and explore the multimodal resources surrounding the students' classroom science experiences and the social aspects of the class and school, which could hardly be gained through simply watching the videos. They also gave insight into how the school setting interplayed with what was going on in the classroom situation, and prompted questions and discussion about the context beyond the lessons observed.

> In our last visit to Taiwan I was struck by the way the teacher orchestrated the unison chanting of the constellation names, and how important poems and singing were. Also the effort gone into the luminescent ceiling. In conversation she talked frankly about the way she organises inquiry in a way that made me suddenly see where she was coming from; this was through looking at her point out the various displays and models and acting out how she got students to participate in role plays. Also she talked about how her practice relates to the norm, and the difficulties of convincing parents, and other teachers, of this approach (Delphi Methodology notes).

Compared to many other comparative studies, the data collection process of this study was uniquely long-term and with many more opportunities for various forms of interactions. Nonetheless, we have been surprised at the time needed to really gain a meaningful understanding of the detail of the other cultural classroom settings. Despite opportunities, it took much longer than anticipated, with the native countrymen having to reiterate and repeat fundamentals.

Understanding Cultural Differences

In addition to knowledge of external systems, it also took time and immersion experiences to develop a sense of the impact which cultural differences had on the science education observed in the video data.

It is not new for researchers to recognise that differences in teaching style or instructional practice stem from deep-rooted cultures of teaching. We often found ourselves using the term 'our culture' to indicate 'national culture' in the discussions. But the emphasis on 'national cultures' of teaching is too simplistic. The idea that teaching at all levels in all schools follows a single national script is overly naïve (Baker and LeTendre 2005). Even different members of a national team may have different views of teaching and learning in 'the national culture', which is shaped by their professional background and personal experience as students, teachers and researchers in classrooms. There is the danger of it relying on personal opinion rather then claims that have been substantiated by more systematic analysis of evidence, and theoretically based. In this study, we took the view that we did not think we were able to 'speak for' our cultures, but when it was necessary, we sometimes, tried to introduce our cultures based on our own experiential understanding. Working in teams brought diverse views within the country team, which helped to guard against a one-sided view of any given local culture. Some shared views also emerged when we were confronted with 'foreign' interpretations of our local data.

As mentioned earlier, there are vivid differences in how each country conceives education and learning, which needs more in-depth reflective discussions to help understand. In sharing and interpreting the classroom data, quite often the existing cultural frames were challenged and broadened through the discussions and understanding of the socio-cultural attributes of the pedagogical practices. An example is what teachers and researchers perceived as 'student-centredness' in different countries. For some, the idea of leaving children to think about a problem for a prolonged period of time was not considered child centred but neglecting the needs of those children who might need more assistance in the reasoning process. The insights from the different research teams and the opportunities to engage regularly and openly in discussing the data allowed the varying concepts to direct this research positively towards discovery. Examples of new knowledge that emerged from the analyses include the classroom settings, teacher discursive moves, approaches toward reasoning and inquiry, forms of representations, and the most challenging scheme of quality teaching (as discussed in previous chapters).

Again, this comes back to the point of bearing in mind at all times that we are searching for quality teaching and learning in science, and that this can exist in a variety of forms in different systems and cultures. We have tried to find common elements that cross over the cases; but this has not always proved very productive or representative. We learned to embrace alternatives and to appreciate the differences. Based on our long-term collaborative experiences, we found cross-cultural studies a joint co-construction of understanding, through which, as Clarke (2004) suggests, educational, philosophical and cultural positions have been given voice in the interpretation of data and the write-up of the stories.

Reflection and Suggestions

The EQUALPRIME study is a learning process for all researchers involved, not only about other cultures and contexts but also a process of constantly reflecting on one's own view on quality teaching in science and in teacher education. In the recently dominant trend of large-scale cross-cultural studies of educational attainments, if cases are distinctive and do not make an effort to extract universal patterns, there is always the question of how applicable the findings could be. As Walker (1986, p. 203) puts it, "descriptive accounts of individual instances may be accepted as true by practitioners but they are unlikely to create appropriate and convincing bases for policy or decision making."

The objective of the study reflects what EQUALPRIME could potentially contribute to the field of cross-cultural comparative study. The study provides the opportunity to look at examples of quality science teaching from the three countries, with the emphasis on observing and learning and not comparing what is 'the best'. At its broadest level, this study attempts to offer new insights and critical perspectives on quality science teaching in some of the contexts and to generate increased awareness and understanding of the factors that lead to different forms of quality teaching. However, each case study is unique in its own way and represents some selection preference of the research teams. A case study could be context bound and not universal, but in the light of other relevant research and theory deriving from it, the patterns and insights may help to illuminate similar processes in context which share some similar conditions. If selection of cases, verification of data, cumulation and generalisation of findings are conducted with rigour, there is scope for the application of results to policy and practice in education. With the inclusion of theoretical criteria and structuring to guide the research and analysis we hope to overcome the potential shortcomings (Schriewer 1992).

A few approaches have been key in making the study possible:

- Having clearly defined research objectives to guide the process and the reiteration of them whenever possible. This is undoubtedly important to all research, but it has been particularly important for an ethnographical study involving a number of teams over a prolonged period of time.
- Shared research repertoires jointly developed by all partners, without one side dominating the process. The repertoires document key decisions, ideas and discussions throughout the study and serve as a principal guideline for the teams to follow in all aspects of the study. The shared repertoire established at the very beginning of the study provided ground rules that all researchers agreed with and established the mutual respect essential for future collaboration. This initial shared repertoire included commitment to professional responsibilities, the ownership of data, the need for cultural respect and authorship of papers. These points were reiterated and refined throughout the process. In the later stage of the research, Delphi methodology was adapted to share further insights among the researchers.
- Even with abundant video data and documentation, regular exchanges within and across the teams at joint meetings throughout the study have been very useful. The periodical discussions in person allow researchers to 'think outside' of their own background knowledge, their past experiences and their values, and hence triangulate and validate their own views for the cross-cultural analysis. Meetings with the teams from other sites and countries enabled a more holistic view of science teaching and brought other insights into selected sections of classroom videos. They allowed discussion and elaboration of data analysis and cross-checking of interpretations of foreign data in order to avoid misinterpretations due to lack of contextual and cultural knowledge. The regular project meetings also provided the chance to build relationships among the academics that were

bound as a team through this project. This was essential for establishing the personal trust and understanding between the research members.

- The opportunities to observe teaching in school visits and to talk to or even work with teachers involved in the project within and outside of one's country have been invaluable, especially in understanding foreign context and culture. Important insights were provided through: interviews where teachers spelled out their philosophies and ideologies; teachers' involvement in discussions about their situation in schools and their practice; commentary on their own videos and on videos of other teachers; and, their reactions and feedback to the analysis shared and the data story told by the researchers. In each case these interactions helped the teams to understand teachers' choices and practices, and how these interlay with the culture and context they are in (see discussions in previous chapters).

In this study, a significant aspect of the research methodology is in its reflective nature; it is by looking at others that we see our own practice, ideas and understandings more clearly. This is particularly true for this project that has the added complexity of not just looking at other practices, but looking at other practices in different cultural settings and under different cultural influences. The cultural comparisons highlighted the nature of the impact of the culture, context and expectations in each society and what we could learn from it.

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Index

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W

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