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# **STUDIES IN SCIENCE EDUCATION IN THE ASIA-PACIFIC REGION**

Edited by

May Cheng, Alister Jones and Cathy Bunting



# Studies in Science Education in the Asia-Pacific Region

Consistent with international trends, there is an active pursuit of more engaging science education in the Asia-Pacific region. The aim of this book is to bring together some examples of research being undertaken at a range of levels, from studies of curriculum and assessment tools, to classroom case studies, and investigations into models of teacher professional learning and development. While neither a comprehensive nor definitive representation of the work that is being carried out in the region, the contributions – from China, Hong Kong, Taiwan, Korea, Japan, Singapore, Australia, and New Zealand – give a taste of some of the issues being explored, and the hopes that researchers have of positively influencing the types of science education experienced by school students.

The purpose of this book is therefore to share contextual information related to science education in the Asia-Pacific region, as well as offering insights for conducting studies in this region and outlining possible questions for further investigation. In addition, we anticipate that the specific resources and strategies introduced in this book will provide a useful reference for curriculum developers and science educators when they design school science curricula and science both pre-service and in-service teacher education programmes.

The first section of the book examines features of science learners and learning, and includes studies investigating the processes associated with science conceptual learning, scientific inquiry, model construction, and students' attitudes towards science. The second section focuses on teachers and teaching. It discusses some more innovative teaching approaches adopted in the region, including the use of group work, inquiry-based instruction, developing scientific literacy, and the use of questions and analogies. The third section reports on initiatives related to assessments and curriculum reform, including initiatives associated with school-based assessment, formative assessment strategies, and teacher support accompanying curriculum reform.

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Edited by May May Hung Cheng,  
Alister Jones and Cathy Bunting

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# 1 Learning, teaching, and assessing science in the Asia-Pacific context

*May May Hung Cheng, Alister Jones, and Cathy Bunting*

## **The Asia-Pacific context: worthy of attention**

The Asia-Pacific region is well known for its wide range of geographical, political, economic, and religious diversity, both among and within the countries in the region. There are countries with vast landmasses (e.g., Russia, China, and India) and also tiny island countries (e.g., the Maldives and Pacific Island countries), there are some of the world's richest economies (e.g., Japan, Hong Kong, and Australia) and some of the poorest (e.g., Bangladesh and Burma), there are societies administered under feudal, communist, and capitalist political systems, and there are a huge number of believers of Christianity, Islam, Hinduism, and Buddhism. Education is by its nature socio-culturally embedded. Given the abundant variety among and within the countries in the Asia-Pacific region, research in both classical areas of science learning and teaching and analysis of trends in the latest curriculum reforms in this region is not only of value to local educators, curriculum designers, and policymakers, but to their counterparts elsewhere who can also gain insights from this highly complex and diversified context.

In particular, the consistent excellent performance of students in parts of the Asia-Pacific region in large-scale international comparisons such as the Trends in Mathematics and Science Study (TIMSS) and the Programme for International Student Achievement (PISA) has generated intense curiosity among local and global scholars regarding how science is being learned and how science learning is supported. According to the PISA 2015 survey (OECD, 2015), nine of the top 15 economies with the highest performance in science assessment are in the Asia-Pacific region, namely Singapore, Japan, Chinese Taipei, Macao (China), Vietnam, Hong Kong (China), B-S-J-G (Beijing-Shanghai-Jiangsu-Guangdong, China), Korea, New Zealand, and Australia. Similar results are also found in the PISA (Program for International Student Assessment) 2009 report, in which five of the six aforementioned (excluding Taipei) are among the top ten. The OECD (2015) report highlights the importance of providing opportunities for students to learn to “think like a scientist” and the quality of science teaching at the classroom level, promoting thinking as a 21st century skill regardless of whether students will pursue science-related careers or not. The report also reveals an association between student science performance and science teaching strategies,

such as the frequency of opportunities for students to “explain scientific ideas”, “discuss their questions”, or “demonstrate an idea”. In addition, students’ science scores tend to be higher when teachers “adapt the lesson to their needs and knowledge” or “provide individual help when a student has difficulties understanding a topic or task”.

Consistent with international trends, there is an active pursuit of more engaging science education in the Asia-Pacific region. The aim of this book is to bring together some examples of research being undertaken at a range of levels, from studies of curriculum and assessment tools, to classroom case studies, and investigations into models of teacher professional learning and development (PLD). It is by no means a comprehensive or definitive representation of the work that is being carried out in the region. Rather, the contributions – from China, Hong Kong, Taiwan, Korea, Japan, Singapore, Australia, and New Zealand – give a taste of some of the issues being explored, and the hopes that researchers have of positively influencing the types of science education experienced by school students.

In addition, we anticipate that the specific resources and strategies introduced in this book will provide a useful reference for local curriculum developers and science educators when they design school science curricula and science teacher education or development programmes. The purpose of this book is therefore to share contextual information related to science education in the Asia-Pacific region, as well as offering insights for conducting studies in this region and outlining possible questions for further investigation. The first section examines features of science learners and learning, and includes studies investigating the processes associated with science conceptual learning, scientific inquiry, model construction, and students’ attitudes towards science. The second section focuses on teachers and teaching. It discusses some innovative teaching approaches adopted in the region, including the use of group work, inquiry-based instruction, developing scientific literacy, and use of questions and analogies. The third section reports on initiatives related to assessments and curriculum reform, including initiatives associated with school-based assessment, formative assessment strategies, and teacher support accompanying curriculum reform.

## **Science learners and learning**

While policymakers tend to compare students’ performance in science learning, an extensive corpus of academic literature in science education reports on students’ attitudes towards and processes of learning science, many with the aim of identifying strategies and mechanisms for improvement. The chapters in this section are consistent with recent research and debates related to students’ interest, science learning attitudes, science inquiry, and the development of models in science classrooms.

Two chapters in this section report on students’ understanding of science concepts. In Chapter 2, Wheijen Chang reports on a Taiwanese study with high school students, showing that the students encountered serious difficulties in

understanding and applying the concept of equilibrium in relation to Newton's first and second laws. The influence of everyday understandings on the development of science concepts was evident. Chang chose to investigate this topic based on the importance of these laws in the study of physics. The gaps in students' understanding were attributed to "sociocultural perspectives in terms of the socially invented nature of physics tools, and students' understandings of scientific ways of seeing and reasoning". Moreover, students from the more prestigious schools did not have any advantages in terms of their responses to the assessment task. Chang chose these concepts based on the importance of these laws in the study of physics. While equilibrium may seem simple to understand, developing a scientific understanding involves making known to students how the ideas may be counter-intuitive to everyday understanding, and helping them to adopt scientific thinking. As argued by Chang, there are likely to be "many more apparently simple terms that significantly confuse students and impede their fluency in physical reasoning. Being aware of the challenges is a first step towards enhanced teaching and learning."

In Chapter 3, Winnie So and her colleagues report on Hong Kong primary school students' use of scientific evidence in the science inquiry process. Specifically, 30 well-structured reports (appropriately 26% of the 115 reports) from the fourteenth Primary Science Inquiries event were randomly selected and analysed according to an analytical framework showing the relationship between the seven concepts of evidence and the quality of the science inquiry. This research is relevant, since students need to apply concepts of evidence in science inquiries, and science projects involving inquiry elements are common at the primary level. Findings showed that students were better able to apply the concepts of identifying variables, carry out fair tests, choose appropriate research instruments, incorporate repeats, and effectively use graphical representations. Choosing measurement values and interpreting results were more challenging for students, these concepts being least embedded in the students' reports. These findings suggest the need to include explicit teaching of procedural aspects within the primary curriculum.

In South Korea, Chan-Jong Kim and colleagues investigated junior high school students' learning processes when co-constructing scientific models (Chapter 4). The teaching strategy, developed by teachers in collaboration with the research team, involved four phases: exploration, small-group modelling, whole-class modelling, and model deployment. The focus of the learning was to use the concept of annual parallax to explain how to measure the distance between close stars. Findings show that the model construction, including the generation, evaluation, and modification of the model, is an evolutionary process. Despite working in small groups, the students' reasons for model modification were shown to often be implicit, although the use of tangible resources, such as table tennis balls, can create links between internal and external representations. Drawing on the findings, the authors discuss how teachers might stimulate student participation in large classes where students tend to be dependent on other students and the teacher, and are less ready to state their own opinions (Lee, 2013). The authors believe that model construction will support the achievement of the



curriculum goals, though further work is needed to explore effective implementation strategies.

Stepping back from a detailed analysis of students' learning in relation to specific science concepts, Yau Yuen Yeung and May May Hung Cheng consider some of the reasons underpinning Hong Kong students' good science performance in international comparative tests (Chapter 5). Apart from identifying implications from socio-political changes, curriculum reform, medium of instruction policy and the Confucian-Heritage Context (CHC), findings from the large-scale international ROSE (Relevance of Science Education) survey were analysed. In particular, strong support from parents and family for children's education seems to be a significant factor driving Hong Kong students' performance in science education. However, findings from the ROSE survey showed that Hong Kong students had comparatively few science-related experiences compared with students of other countries, except in relation to the use of hand tools and computers. They also preferred jobs with a high degree of autonomy and independence rather than jobs requiring creativity in S&T. The authors call for further systematic investigations to identify factors or evidence associated with good student performance in science.

## **Science pedagogy**

Recognizing the critical role of the teacher in scaffolding students' engagement and learning in school science, the second section of the book brings together examples of pedagogical strategies constructed to facilitate students' science learning. In many cases, these chapters acknowledge the education and curriculum reforms implemented in the relevant education contexts in order to support the development of more competitive future generations. Since the 1990s, an increasing amount of content related to Science, Technology, and Society (STS) has been integrated in Taiwanese school science textbooks (Tsai, 2000). The nature of science, which has been explicitly articulated and emphasised in curriculum documents in North America and Europe over the last 20 years is now starting to be integrated into Asian science education (Wong, Hodson, Kwan, & Yung, 2009). The goal of developing students' scientific literacy has been promoted in science curriculum reform documents such as the Thailand Office of the National Education Commission (2003), the Chinese Ministry of Education (2001), the Australian Education Council (1994), the Bangladesh Ministry of Education (2000), and the Hong Kong Curriculum Development Council (2002). Corresponding to the emergence of this newly articulated objective, considerable changes have been required in relation to the content and methods of science teaching, and inquiry-based science pedagogies have been promulgated among educators in the Asia-Pacific region (Hofstein, Navon, Kipnis, & Mamluk-Naaman, 2005).

There is, in fact, an active area of research on pedagogical innovations in the Asia-Pacific region, and the second section of this book includes six chapters related to science teaching pedagogies with contributions from Taiwan, Singapore, Hong Kong, Japan, and Australia. In Chapter 6, Hsiao-Lin Tuan and

Chi-Chin Chin consider how science inquiry is addressed in primary and secondary curricular goals and classroom settings in Taiwan. Research findings from the last 20 years are reviewed. They illustrate how Taiwanese science teachers have addressed inquiry-based instruction in school science class settings and teacher education programmes, with findings related to student learning of science inquiry skills, attitudes towards learning science, and students' creativity, argumentation and problem-solving skills. Given the curriculum directions and efforts of science teachers to improve their inquiry-based instruction, the authors conclude that inquiry-based instruction is likely to continue to play an important role in science education in Taiwan.

Kok-Siang Tan introduces the shifts towards a focus on the holistic development of students in Singapore schools and reports on the use of 'reversed analogies' in school science (Chapter 7). This approach, called a 'cognitive-affective integrative' pedagogy, uses science concepts (as the analogue) to illustrate an appropriately identified social value or life skill (the target). Such an approach is considered to infuse affective learning opportunities into the school science curriculum without significantly changing how science is taught in class. Of course, as with analogies, appropriate selection of the reverse analogies is required, and the chapter provides some useful examples. The project suggests on ways to support students to develop positive social values and life skills through using 'reversed analogies'. The challenge remains how to ensure students' learning of scientific concepts while at the same time achieving these affective learning targets.

The use of group work in primary science classrooms was the theme of two chapters. In Chapter 8, Dennis Fung first provides an overview of group work in science from an international perspective before reporting on relevant policy shifts to support group work in Hong Kong primary schools. In order to investigate the impact of group work in science classrooms, four Grade 5 classes from two primary schools participated in a quasi-experimental research project. The participating science teachers attended professional development workshops and designed teaching interventions in their science lessons. Data were collected from both intervention and control classrooms. Students in the intervention classes participated in problem-solving activities, including discussions, debates, presentations and reflection, whereas students in the control class worked independently. Teachers described the atmosphere in the intervention classrooms as interactive and supportive, with students motivated to engage in the group activities and gains in terms of the students' performance in both cognitive and affective areas. Students reported that group work increased both the *collaborative* and *competitive* atmosphere within their classrooms, with a shift in focus from individual success to group success. Fung points to the importance of teachers' understanding of their roles in facilitating group work and how this may support student learning.

Staying with group work but investigating its impact on supporting inquiry-based pedagogies in Singapore, Joanna Oon Jiu Ong and her colleagues sought Year 4 students' accounts of their science learning experiences using co-generative dialogues (Chapter 9). The study therefore focuses on student views of what it means to be a learner of science in their classrooms. A key finding was

that interpersonal interactions were more memorable to the students than the actual science content – and that sometimes these interactions, while looking like ‘off-task’ behaviours, were actually important in helping students to recall their conceptual learning. The study calls for attention to student-teacher relationships and teacher professional development opportunities highlighting this particular aspect.

The important role of teacher professional development and learning (PLD), highlighted by Ong et al. is picked up by John Loughran in Chapter 10. Specifically, this chapter describes a long-term PLD programme underpinning a whole-school approach to developing primary students’ scientific literacy in Australia. Throughout the PLD programme, the ‘why’ of teaching particular subject matter content in particular ways was an important feature of discussions, intervention designs, and teacher reflections. In other words, pedagogical content knowledge (Shulman, 1986) was a focus. Another key aspect of the PLD programme was the writing of reflective case studies by participating teachers. This approach was intended to support participants’ reflection on the ways in which their learning from the PLD was enacted in their classroom practice, and to facilitate a shift in their teacher talk from the ‘what and how’ to the ‘why’ of teaching. Support from school leadership was another key ingredient of change. As a result of participating in the PLD over three years, the school described in the chapter developed a multi-domain approach to ensuring that their students’ learning of science was connected, meaningful and relevant, rather than something that only happened in the timetabled period known as ‘science’. This reflected changes in the teachers’ beliefs about scientific literacy and their vision for meaningful learning.

In the absence of in-depth PLD, and even when it is present, textbooks and other related resources often influence the curriculum implemented in the classroom. This is explored in Chapter 11 by Manabu Sumida, who used text analysis methods to investigate the use of questions in upper primary science textbooks in Japan. Findings suggest a much more frequent use of ‘yes/no’ questions compared with the use of ‘why’ questions. In other words, although primary science classes include hands-on activities such as observations and experiments, the questions aimed at reinforcing the significance of these activities tend to be simple and limited in number. Reinforcing this, a word mapping analysis showed a focus on parts of concrete scientific objects. Manabu points to the importance of using language that encourages students to think, express their scientific ideas, and engage in science learning as a social activity. The study has implications for textbook publishers, teachers, and PLD providers, and the methods used may be useful for similar investigations in the use of language in other subjects, as well as in science in other cultures.

## **Science assessment and curriculum reform**

While the previous section’s focus on classroom interactions used specific case studies to exemplify the arguments being made, the chapters in this section

take a step back to consider the implications of assessment and curriculum reforms. In Chapter 12, May May Hung Cheng and Zhi Hong Wan report on the similarities and differences between assessment in the senior secondary physics curricula in Hong Kong and Mainland China based on an analysis of the curriculum documents. Most prominent are differences related to the use and relationships between formative and summative assessment: The introduction of school-based assessment in Hong Kong is seen to be an effort to bridge formative and summative assessment. While the factors explaining the differences in the two systems are identified, the authors call for clarity in future directions and sustained support for teachers such that the implementation of school-based assessment may continue despite a strong examination culture in Hong Kong.

In line with an emphasis on assessment for learning, Chu and Wong report in Chapter 13 on a study of pre-service science teachers identifying their prior understanding and implementation of formative assessment strategies in their classrooms. Findings showed varied responses among pre-service teachers during a teaching intervention, and their beliefs in the use of inquiry and constructivist principles in relation to formative assessment. However, the pre-service teachers were generally less prepared to use classroom discourse to promote formative assessment. The authors relate the findings to the education context in Singapore where there are high expectations for teachers and students because of the high-stakes examination system.

An even broader review of curriculum and assessment reform is provided by Cathy Bunting and Alister Jones using the context of New Zealand (Chapter 14). As a small country with a robust infrastructure, conditions should favour the successful implementation of curriculum reform. However, assessment policies significantly influence the foci of school teaching and learning programmes here as they do elsewhere. Teacher change can also be difficult to achieve. Support is provided in the form of wider political support for effective science education, leading to multiple resource initiatives. However, teacher PLD and assessment criteria aligned with curriculum goals and political rhetoric continue to be needed.

## **Concluding thoughts**

This book is intended to bring together a range of perspectives on science education curricula, implementation and future directions from across the Asia-Pacific region. Positive shifts can be identified in terms of engaging and meaningful science learning opportunities initiated by teams of teachers and education researchers, with broad foci of the work – from students’ conceptual development, to students’ engagement with the nature of science, learning through group work, and more holistic views of education, including education through science. While the issues and concerns highlighted in the chapters of this book are consistent with recent debates in science education, the discussions provide insights for the future direction of research.

In the first section of the book, Chapters 2 and 3 analyse students' understandings of Newton's Laws and the application of concepts related to scientific inquiry. Chapter 2 highlights the implications of teachers being aware of how scientific concepts may be counter-intuitive to everyday understandings and of the need to help students develop scientific understandings. Chapter 3 identifies primary students' use of concepts related to scientific inquiry in science fair projects. While some concepts are more commonly applied, choosing measurement values and interpreting results are less frequently used. The findings and implications of these chapters are consistent with recent studies related to scientific inquiries in other parts of the world. For example, Haug and Ødegaard (2014) related teachers' talk and primary students' development of knowledge of words related to different phases of science inquiry. Their findings suggest that students' development of conceptual knowledge is related to their involvement in the discussion, or active participation. Further, Paul, Lederman, and Groß (2016) interviewed youth participants of a science fair and revealed five subdomains of learning: procedure, purpose, material, control, and time. Drawing on the findings, they argue for embedding open or authentic inquiry in school science lessons. Students' understanding of conceptual knowledge and the application of concepts in scientific inquiry through classroom teaching and projects like science fairs therefore continues to be a focus in recent research in different parts of the world. While we notice the similarities in the research trend, researchers and teachers may need to be aware of differences in sociocultural contexts where, for example, everyday understanding of scientific terms may differ.

The study of students' attitudes towards science learning is another focus of science education research, picked up by Yeung and Cheng in Chapter 5. Other research, for example, by Blankenburg, Höffler, and Parchmann (2016), has also investigated primary students' interest in science and suggested implications for science curricula which may address the interests of students of different genders as well as the needs of future societies. With changes in social, economic, and political contexts driving curriculum reforms in different parts of the world, it is important for science educators to keep developing our understandings of students' learning of science and how attitudes to science learning develop. In other words, research related to students' interest in and attitudes toward science learning remains important as such understanding should be used to inform the design and implementation of innovative learning and teaching strategies.

Three of the chapters in this book focus on specific areas of science teaching and learning, that is, the use of models, analogies and questions in textbooks. Kim and colleagues (Chapter 4) and other researchers (e.g., Cheng & Lin, 2015) have investigated students' views on scientific models and their ability to develop the models. As Kim and colleagues argue, it is important for teachers to understand how teachers adopt these pedagogical approaches, for example, students' developing and using models in large class settings such as those commonly found in the Asia region. Both Kok Siang Tan (Chapter 7, introducing 'reverse analogies') and Manaba Sumida (Chapter 11, examining

the use of questions in textbooks) propose that their studies may be applied in other subject areas or languages. In addition to identifying new directions for research, these chapters provide examples of innovative pedagogies involving the use and development of models, and questions in textbooks to facilitate science understandings as well as providing affective learning opportunities in science classrooms.

In the section on science pedagogy, four chapters discuss the use of inquiry-based instruction, group work, and the development of a multi-domain approach to facilitating students' science learning through teacher professional development opportunities. Although the authors have explored different recent questions and adopted different research methods, their findings collectively point to innovative strategies. Tuan and Chin (Chapter 6) summarise action research related to inquiry-based instruction in Taiwanese science classrooms. Their efforts echo recent research in other parts of the world, such as Sesen and Tarhan (2013) in Turkey. Similarly, the importance of science teacher professional development and learning emphasised by Loughran (Chapter 10) is in agreement with other recent studies. For example, Nowicki, Sullivan-Watts, Shim, Young, and Pockalny (2013) examined science inquiry lessons delivered by experienced science teachers and student teachers and found that the accuracy of the science content was highly correlated with the use of kit-based resources supported by professional development. Based on a study of group work in science classrooms in Hong Kong, Dennis Chun Lok Fung in Chapter 8 highlights the importance of teachers' understanding of their roles in facilitating group work, while Joanna Oon Jee Ong and her colleagues (Chapter 9) call attention to student-teacher and peer relationships among students when teachers plan, implement, and reflect on their science teaching.

Two chapters in the section on science assessment and curriculum reform look specifically into science assessment at different levels. These two chapters (Chapters 12 and 13) point out important considerations related to science assessment at the system level and the classroom level. These chapters point out that the implementation of school-based assessment in Hong Kong or China and the assessment for learning strategies in Singapore is under the influence of the examination-oriented education system, and that secondary students participate in high-stakes public examinations. Both chapters highlight the importance of providing professional development or support for science teachers and pre-service teachers to successfully incorporate school-based formative and/or summative assessment strategies in science classrooms. Implementing school-based assessment at a system level will also require strategies to address the challenges related to issues of objectivity, teachers' expertise and workload.

As pointed out earlier, the Asia-Pacific region represents a wide range of different cultural and political histories, and their different influences can be variously seen across the chapters of this book. Nonetheless, science education is heralded as important by many of the countries' national policies, and teachers are called to not only support students' learning, but to inspire them in that learning. We, therefore, conclude with the acknowledgement that it is in the classroom that real

change is ultimately experienced, and that across the Asia-Pacific region there are large numbers of teachers continuously balancing complex interactions between the curriculum, school assessment policies, parent and community expectations, and students' engagement in science learning at school.

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## 2 Taiwanese students' 'equilibrium' reasoning

### Fluency in linking Newton's first and second laws

*Wheijen Chang*

#### Introduction

What are the relations between Newton's three Laws of Motion? More specifically, how can Newton's first law help solve problems involving Newton's second law? Newton's first law is valid under the condition of nil total force or zero acceleration ( $\Sigma \vec{F} = 0$ ,  $\vec{a} = 0$ ), a condition called the 'state of equilibrium'. Newton's second law states the relation between total force ( $\Sigma \vec{F}$ ) and acceleration ( $\vec{a}$ ), i.e.,  $\Sigma \vec{F} = m\vec{a}$ . The ability to determine the condition of Newton's first law is crucial for reasoning through problems involving Newton's second law, since the condition of  $\Sigma \vec{F} = 0$  or  $\vec{a} = 0$  usually serves as the basis for deriving the equations associated with  $\Sigma \vec{F} = m\vec{a}$ .

This article argues that when reasoning problems related to Newton's first law, many students tend to be confused about the conditions for equilibrium, and their inability to examine equilibrium may lead to their failure to solve problems involving Newton's second law. In order to enhance students' understanding of Newton's Laws, the concept of equilibrium should be highlighted in the teaching design.

Based on a review of seven high school physics textbooks in the United States, the Physics Textbook Review Committee (1998) critiqued that "a more general flaw is the way that physics is presented as a series of disconnected laws and rules. The books dutifully present Newton's three laws, then proceed to ignore them in developing new concepts" (p. 299). For example, the links among Newton's three laws may be omitted, as is the link between Newton's third law and the conservation of momentum. Efforts to integrate physics principles are crucial to enhancing students' understanding of physical terminologies and fluency in applying physics laws (Buncick, Betts, & Horgan, 2001; Chang, 2011).

Rooted in the constructivist view of learning, Posner, Strike, Hewson, and Gertzog (1982) initiated the Conceptual Change Model, which suggested that instructional design provide *anomalies* to stimulate students to abandon their naïve ideas and shift toward scientific conceptions. In order to successfully determine the state of equilibrium, students need to thoroughly comprehend the concepts of 'force' and 'acceleration'. However, Reif and Allen (1992) investigated students' reasoning about acceleration and found several prevalent pitfalls: 1) lack of distinction between velocity ( $\vec{v}$ ) and acceleration ( $\vec{a}$ ), for example,

inappropriately referring to the state of being ‘at rest’ ( $\vec{v} = 0$ ) as ‘equilibrium’ ( $\vec{a} = 0$ ); 2) unifying the directions of acceleration and motion; and 3) viewing the acceleration of circular motion as always toward the center. In addition, students were found to embrace a variety of misconceptions regarding ‘force’, for example, 1) motion implies force, 2) force takes time to gradually ‘accumulate’ (temporal delay), and 3) objects have *memory*, allowing them to keep their original motion, even circular motion (Clement, 1982; Halloun & Hestenes, 1985). Even the greatest physicist, Newton, was found to overuse the idea of ‘equilibrium’ when explaining the circular trajectory of planetary motion in his early version of the *Principia*. He also initially adopted the fictitious *centrifugal* force to ‘balance’ gravity (Steinberg, Brown, & Clement, 1990). Therefore, naïve conceptions regarding force and acceleration are commonly held by students, which may impede their reasoning of equilibrium and of solving problems of Newton’s Laws.

On the other hand, scientific knowledge is regarded as not simply the discovery of objective truths about the universe, but rather interpretations based on the *invention* of scientific tools gradually established by the scientific community (Driver, Asoko, Leach, Mortimer, & Scott, 1994). For example, the concept of ‘acceleration’ was ‘invented’, rather than ‘discovered’, by Galileo. Arons (1990) noted, “Galileo was explicitly conscious of the fact that he was defining new concepts and not ‘discovering’ objects, (when) he argues about the alternative definitions of acceleration” (p. 39). Arons also stated, “Galileo rejects the former ( $a = \Delta v / \Delta s$ ) . . . and adopts the latter ( $a = \Delta v / \Delta t$ ) largely because he has the deeply rooted hunch that free fall . . . is uniformly accelerated” (p. 30).

Science knowledge is usually discrepant from everyday conventions in terms of 1) epistemological underpinnings 2) ontological assumptions of the terminologies and 3) adoption of novel tools, which constitute the learning demands (Leach & Scott, 2002). Therefore, teaching physics should aim at helping students grasp scientific ways of seeing (O’Loughlin, 1992). Driver et al. (1994) contended,

The role of the science educator is to mediate scientific knowledge for learners, to help them to make personal sense of the ways in which knowledge claims are generated and validated, rather than to organize individual sense-making about the natural world.

(p. 6)

Understanding of physics concepts requires the integration of multiple representations, and repeated practice is necessary for students to gain fluency in utilizing the disciplinary discourse (Airey & Linder, 2009; Chang, 2011).

This study investigated Taiwanese high school students’ reasoning about equilibrium and their fluency in utilizing this reasoning to solve problems involving Newton’s Laws. The research tool was developed as follows: 1) during the topic of Newton’s Laws of Motion, an open-form test including 16 questions was

Table 2.1 Percentages of correct responses to each question by the students from the different schools (empty boxes indicate questions not presented to students.)

School	n	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
A	187	17%	27%	17%	96%	62%	34%	87%	40%	31%	45%	38%	38%	6%
B1	199	14%	22%			46%			11%		51%			
B2	42		17%	5%					14%		33%			
B3	137			17%				79%			47%			
B4	146				98%		14%						31%	
B5	109				96%		16%			27%		29%	29%	6%
B6	100									19%		18%		13%

distributed to more than 200 university students, and 2) one-on-one diagnostic interviews with 15 students were carried out. Then, 13 multiple-choice questions regarding equilibrium were devised as the tool of this study. Two academic levels of high schools answered the 13 questions relating to equilibrium of motion: 1 prestigious school (A) and 6 conventional schools (B1–B6). In Taiwan, students are streamed by a Unified Entrance Examination when allocated their high schools. Based on the lowest acceptance score of the Entrance Examination, the threshold percentile rank of School A was PR = 97%, while those of schools B1–B6 ranged from PR = 71% – 90%. The students from School A answered all 13 questions, while those from schools B1–B6 were asked to answer 3–6 questions. In total, 920 high school students took the tests. Their performance is discussed next (Table 2.1).

## Results

The percentages of correct answers for each question are tabulated in Table 2.1, along with the number of participants (n) from each school.

The students' performance on the 13 questions regarding equilibrium of motion is discussed in two categories: 1) determining of the state of equilibrium (Newton's first law), and 2) applying 'equilibrium' to Newton's second law ( $\Sigma \vec{F} = m\vec{a}$ ). Category 1 contains questions 1 to 6, and questions 7 to 13 are for category 2. In order to avoid giving the students too many hints, the order of the questions listed in Table 2.1 is not the same as that of those presented to the students.

### 1 Determining the state of equilibrium

Figures 2.1 to 2.6 depict the contexts of Q1 to Q6. Among the six situations (shown in Figures 2.1–2.6), which cases are in the state of equilibrium – i.e.,  $\Sigma \vec{F} = 0$  and  $\vec{a} = 0$ ? The correct answer is none, but the students were found to encounter serious difficulty comprehending the concept of equilibrium. Their confusion is discussed in terms of three aspects: at rest  $\neq$  equilibrium, equilibrium point  $\neq$  equilibrium, and free fall  $\neq$  equilibrium.

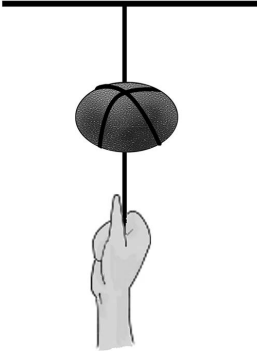


Figure 2.1 Quickly jerk the lower string and break it

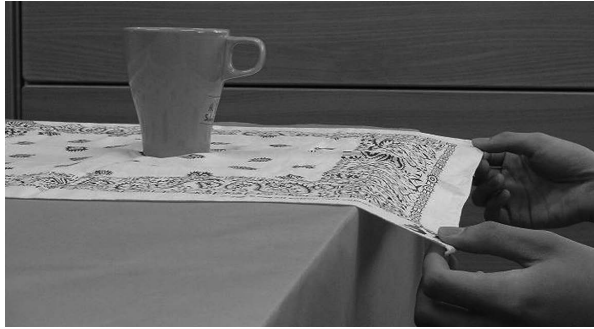


Figure 2.2 Quickly pull the tablecloth without shifting the dishes

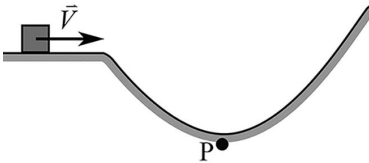


Figure 2.3 Determine the direction of acceleration at point P, when the block slides along the frictionless path



Figure 2.4 The cheerleader jumps up and reaches the top



Figure 2.5 A parachutist has just jumped out of an airplane and is experiencing “free fall”

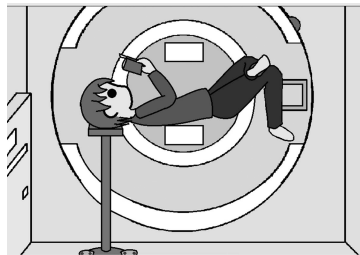


Figure 2.6 An astronaut “floating” in a space shuttle near the Earth experiences weightlessness

*i At rest  $\neq$  equilibrium*

For situation #1, since the lower string breaks, the tension of the lower string must be greater than that of the upper string; thus, the anvil experiences a net downward force (Sandin, 1990). Similarly, in case #2, the dishes on top of the tablecloth should have kinetic friction force exerted on them ( $F_{fk} = \mu_k \cdot N$ ), which is *not* negligible regardless of how fast the man pulls the tablecloth (Hudson, 1985). Cases #1 and #2 demonstrate that when objects are at rest, they are not necessarily in equilibrium ( $v=0$ , but  $a \neq 0$ ). The referenced literature also indicates that cases #1 and #2 are often inappropriately used as examples of Newton's first law.

Table 2.1 shows that in case #1, only 17% of the A1 and 14% of the B1 students correctly reasoned that the anvil's speed is the only negligible variable. As many as 80% inappropriately regarded it as 'force equilibrium', where 36%–43% selected the option of 'too fast to transfer the jerk', implying the misconception of temporal delay (Halloun & Hestenes, 1985). Similarly, in case #2, only 17%–27% correctly distinguished that *only* the velocity of the dishes is negligible, whereas 39%–66% incorrectly perceived case #2 as 'equilibrium' – i.e.,  $\Sigma \vec{F} = 0$  or  $\vec{a} = 0$ .

*ii Equilibrium points  $\neq$  equilibrium*

Second, the so-called equilibrium points are actually not 'equilibrium', such as point P in case #3. According to the components of acceleration,  $\vec{a} = \vec{a}_t + \vec{a}_c$ ; although the tangential acceleration at the equilibrium points is zero, the centripetal accelerations are not. Thus, objects moving at these 'equilibrium points' (in the context of energy) are *not* equilibrium (in Newton's Laws).

Question 3 asked the students to determine the acceleration of the block sliding at point P. Only 5%–17% of the students correctly reasoned the centripetal component (in an upwards direction). As many as 43% of group A answered  $a = 0$ , implying that even the students at the prestigious school tended to overuse the concept of equilibrium. Although groups B2 and B3 were found to have lower percentages (25%–26%) of students overusing the idea of equilibrium, many of them (36%–41%) selected the option of ( $a: \rightarrow$ ), implying confusion between acceleration and velocity.

*iii Free fall  $\neq$  equilibrium*

Third, students may confuse 'free fall' with 'free of force'. The contexts of #4, #5 and #6 all relate to free fall, and the net force is equal to the gravitational force ( $F_{\text{net}} = F_g$ ) in all three examples. Thus, none of these situations is an example of equilibrium, and in no case is the acceleration or net force zero.

When determining the acceleration of the cheerleader when reaching the highest point (Figure 2.4), almost all students (96%–98%) in groups A, B4, and B5 correctly denoted the downward direction. The results indicated the students' ability to distinguish between acceleration and velocity ( $\vec{v} = 0$ ,  $\vec{a} \neq 0$ ) in this



context. However, regarding Figure 2.5, only 61% of A1 and 46% of B1 students correctly selected that both the net force and the acceleration of the parachutist are downwards. Up to 45% of B1 and 33% of A1 students' answers indicate a confusion of 'free fall' with 'force free' ( $\Sigma \vec{F} = 0$ ). This incorrect connection was found to be even more widespread in the case of the space shuttle (Figure 2.6), where 43%–59% of the A1, B4, and B5 groups regarded the total force exerted on the astronaut as being zero.

## 2 *Applying equilibrium to Newton's second law*

When applied to Newton's second law ( $\Sigma \vec{F} = m\vec{a}$ ), equilibrium is usually a crucial foundation for deriving the required equations in order to determine individual force or acceleration. Students, therefore, need to first examine whether equilibrium is held, a task which was either ignored or very challenging.

Let us first consider whether equilibrium held in each of the cases presented in Figures 2.7–2.13. Figures 2.7 to 2.13 demonstrate the contexts of Q7 to Q13. Then, for those that fulfill the condition of equilibrium, how can the strategy be applied? The students' difficulties were twofold: adopting or ignoring considerations of equilibrium, and overusing the condition of equilibrium.

### *i Adoption/ignorance of the strategy of equilibrium*

Figures 2.7 and 2.8 are in a condition of constant velocity, and thus fulfill the state of equilibrium – i.e.,  $\Sigma \vec{F} = 0$ . However, the students' grasp of equilibrium was found to vary for the different contexts. Figure 2.7 was extracted from the Mechanics Baseline Test (Hestenes & Wells, 1992), which requires the adoption of equilibrium and mathematical ability of vector analysis – i.e.,  $\Sigma \vec{F}_x = 0$  and  $\Sigma \vec{F}_y = 0$ . Up to 79%–87% of the A and B3 groups successfully reasoned the relations of  $N = W$  and  $F > k$ . In contrast, when determining the friction of the interfaces between blocks A and B and B and C, in Figure 2.8, only 40% of School A students and 11%–14% of the B1 and B2 groups correctly selected the option that “friction exists between A & B, but not between B & C”. Many students (46%–76%) inappropriately perceived that friction is exerted at all interfaces when the blocks are moving. This common mistake indicates the naïve idea that “moving requires force” and ignorance of the impact of equilibrium.

A similar example is found in Figure 2.9: determining the magnitude of friction. Before starting any mathematical calculation, the question requires students to consider whether the block is moving – i.e., whether the total external force exceeds the maximum static friction. The answer is no, the block is at rest, and so fulfills the condition of equilibrium. By means of  $\Sigma \vec{F} = 0$ , the (static) friction is evaluated by the parallel net external force ( $F_{fs} = mg - F \cdot \sin\theta$ ). In other words, the popular formula of  $F_f = \mu N$  becomes invalid. However, 22%–38% of students who selected  $F_f = \mu_k N$ , and 11%–33% who chose  $F_f = \mu_s N$ . Only 31%, 27%, and 19% of

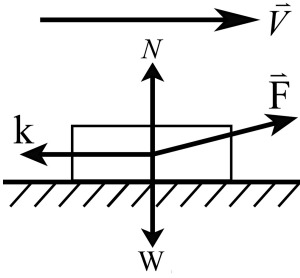


Figure 2.7 Compare the magnitudes of  $N$ ,  $W$ ,  $F$ , and  $k$ , when the block is moving at constant velocity

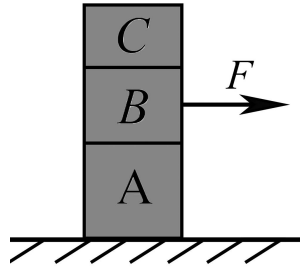


Figure 2.8 Which interfaces have friction when the three blocks, exerted by  $F$ , maintain constant velocity?

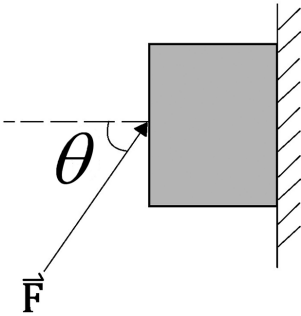


Figure 2.9 Given  $F$ ,  $\theta$ ,  $\mu_s$ , and  $\mu_k$ , determine the frictional force reacted on the block, when it is originally at rest

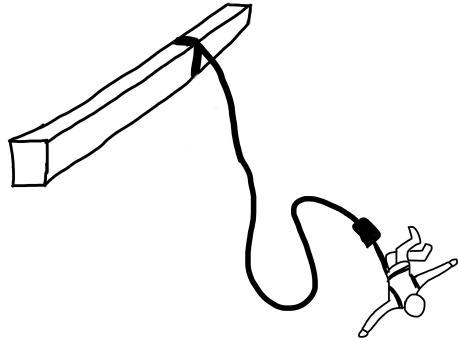


Figure 2.10 Determine the total force and tension at the moment the bungee jumper reaches maximum speed

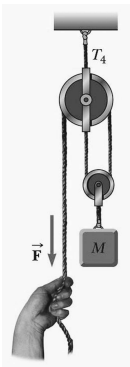


Figure 2.11 Estimate  $T_4$  with the given mass of the block ( $M$ ) and the force ( $F$ ) exerted by the hand

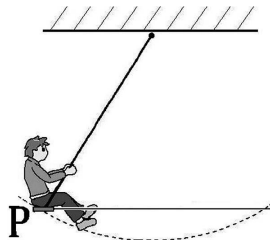
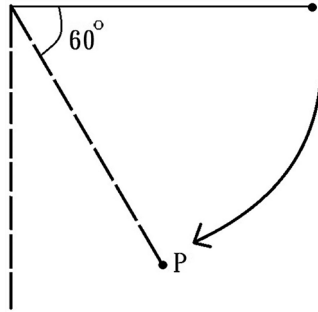


Figure 2.12 Compare the tension and gravity when the boy reaches the highest point (P) of his swing



*Figure 2.13* Calculate the tension of the simple pendulum when it swings from horizontal to  $60^\circ$

the A1, B5, and B6 groups respectively selected the correct option, showing their fluency in utilizing the equilibrium strategy.

The last example fulfilling equilibrium is Figure 2.10. When the bungee jumper reaches his maximum speed, the instantaneous acceleration is zero, thus the total force is zero. Among the four groups, 45% of A1 and 33%–51% of the B1, B2, and B3 students answered correctly. A considerable proportion of students (31%–44%) selected the incorrect option that the man reaches his maximum speed right before the rope starts to pull up. The idea of “being pulled back by the rope” may be effective in many everyday experiences, but this intuitive idea is inadequate for this equilibrium context. The students from School A did not have a background advantage and ignored the equilibrium strategy when answering this question.

In sum, four examples associated with the strategy of equilibrium have been discussed. Except for the question extracted from the literature (Figure 2.7), many of the participants (49%–89%) did not adopt the strategy of considering equilibrium when reasoning the individual force or acceleration (Figures 2.8 and 2.10). The results highlight that the students’ difficulty in reasoning individual force may not be due to the difficulty of the mathematical skills required (such as Figure 2.7), but rather may be because of the overuse of popular formulas (such as Figure 2.9) and of their intuitive ideas associated with everyday experiences (such as Figures 2.8 and 2.10). Therefore, the crucial strategy of considering equilibrium tends to be overlooked when encountering popular formulas and everyday experiences.

### *ii Overuse of equilibrium*

The prior section described how the students commonly ignored a consideration of equilibrium when solving Newton’s second law problems. This section examines how the students could avoid the overuse of the equilibrium strategy when  $\Sigma \vec{F} = 0$  is not fulfilled.

In Figure 2.11, with an arbitrary known force of pull ( $F$ ) and mass of the block ( $M$ ), the pulley system may move with acceleration, which violates the condition of equilibrium – i.e.,  $\Sigma \vec{F} \neq 0$ . The force upwards should not be balanced with that of the downwards force, i.e.,  $T_4(\uparrow) \neq F + Mg(\downarrow)$ . However, when determining  $T_4$ , a large proportion of students (48% of A1, 50% of B6, and 39% of B5) inappropriately selected option (C) – i.e.,  $T_4 = F + Mg$ , implying an overuse of the equilibrium strategy. Only 38% of A1, 29% of B5, and 18% of B6 correctly answered that  $T_4 = T_1 + T_2 + T_3 = 3F$ .

Lastly, Figures 2.12 and 2.13 include two-dimensional motions. However, before applying the mathematical skill of vector analysis, the students needed to examine conceptually the validity of the equilibrium strategy. Regarding Figure 2.12, before deriving any equation, the students were required to figure out which component, if any, fulfills the condition of equilibrium – i.e., vertical, horizontal, tangential, or radial? Since the instantaneous speed at point P is zero, the radial component is equilibrium ( $a_c = v^2/r = 0$ ), but not the tangential component. Thus, the weight should be divided into the tangential and radial components, and the radial component is balanced with the tension ( $\sphericalangle = \sphericalangle$ ). Gravity is thus greater than tension. Only 38% of the A and 29%–31% of the B4 and B5 students grasped the correct component of equilibrium. There are as many as 46%–51% of the three groups mistakenly selected the option showing an inadequate orientation of the equilibrium strategy – i.e.,  $\uparrow = \downarrow$ . Many students started from the 'balance' of up and down components without seeking the reason when figuring out this question.

The last question, shown in Figure 2.13, is actually very challenging since when the pendulum swings at point P, the strategy of equilibrium is invalid for any component. The tension of the string needs to be evaluated via the conservation of mechanical energy to calculate the speed; then one can determine its centripetal acceleration, and finally obtain the tension. Very few (6%–13%) of the A1, B5, and B6 groups selected the correct option, with the students from School A not having any advantage. In fact, random guessing of the multiple-choice answers could lead to the mismatch of the students' performance and their background. Most of the participants were found to continue to embrace the invalid strategy of 'equilibrium' in this question, either for the radial component (12%–66%) or for the vertical component (20%–66%). When incorrectly

Table 2.2 Comparison of percentage correct answers for students from the prestigious school (A) and those from the conventional schools (B1–B6)

Question	1	2	3	4	5	6	7	8	9	10	11	12	13
A (n = 187)	17%	27%	17%	96%	62%	34%	87%	40%	31%	45%	38%	38%	6%
Average of B1 – B6	14%	21%	14%	97%	46%	15%	79%	12%	23%	48%	24%	30%	9%
n of Sch. B	199	241	179	255	199	255	137	251	209	378	209	255	209
X <sup>2</sup> test	0.66	2.10	0.64	0.24	9.93*	21.9**	3.69	46.1**	3.22	0.45	9.11*	3.10	1.27

\*p < 0.01 \*\*p < 0.001

adopting the equilibrium strategy, the A school students tended to aim at the radial component ( $\hat{r}=\hat{v}$ ), whereas the B5 group tended to reason with the vertical orientation ( $\hat{r}=\hat{v}$ ).

In sum, when responding to equations concerning Newton's second law, the students were found either to ignore the condition of equilibrium or to grasp an invalid orientation, leading to the failure of considering equilibrium.

### **Differences between the prestigious school and the conventional schools**

A chi-square test was used to examine the performance difference between the prestigious school and the conventional schools. Table 2.2 shows that students from the prestigious school outperformed students from the conventional schools in terms of the averages of 11 of the 13 questions (not #4 and #10). However, the differences were statistically significant for only four of the questions.

When determining the state of equilibrium in Questions 1–6, students from the prestigious school (A) were found to significantly outperform their cohort only in questions 5 and 6, which both required the ability to distinguish the difference between free fall and equilibrium. It should be noted here that in Questions 1 and 2, students from School A performed about as poorly as the B school cohorts. The common confusion about equilibrium, even among students in the prestigious school, may be attributed to the inappropriate examples of Newton's first law introduced by many textbooks (Hudson, 1985; Sandin, 1990).

Regarding the application of the equilibrium strategy to Newton's second law (Questions 7–13), students from School A were found to have a background advantage when answering Questions 8 and 11. These students seemed to be less likely to hold the naïve idea that 'motion refers to friction' (Q8) and the ability to select the appropriate system (Q11). However, students from School A may have lost their background advantage in avoiding overuse of the equation of friction ( $F_f = \mu N$ ) (Q9), and in grasping the effective orientation of equilibrium (Q12 & Q13). The two tasks require *conceptual reasoning* of whether (and where) equilibrium holds.

In order to increase students' abilities to solve problems related to Newton's Laws of Motion, the ritual of "conceptual reasoning before manipulation" may need to be enhanced, and the determination of "the condition of equilibrium" can be a crucial part of conceptual reasoning.

### **Discussion and conclusions**

The task of determining the state of equilibrium ( $\sum \vec{F} = 0$ ,  $\vec{a} = 0$ ) should be an important component when learning Newton's first law, since the equilibrium strategy is crucial for reasoning problems involving Newton's second law. However, our research found that the Taiwanese high school students failed to determine the conditions of equilibrium in various contexts. In addition, when dealing

with problems involving Newton's second law, such as evaluating individual force or acceleration, they ignored the strategy of equilibrium when it was required, but overused the strategy when the conditions did not hold.

The major difficulties indicated by the investigation may be categorised into two aspects. The first relates to the influence of everyday experiences, some of which are reported in the literature, for example, temporal delay (Question 1) (Halloun & Hestenes, 1985), friction existing while moving (Question 8), and equating being momentarily at rest with nil acceleration (Question 2) (Reif & Allen, 1992). Although these ideas are common in everyday thinking, they are discrepant with scientific perspectives. In order to trigger a shift from everyday ideas to scientific conceptions, providing demonstrations that serve as anomalies may fulfill the condition of dissatisfaction proposed by the Conceptual Change Model (Posner et al., 1982).

However, the second type of difficulty that the students encountered is related to sociocultural perspectives in terms of the socially invented nature of physics tools, and students' understandings of scientific ways of seeing and reasoning (Driver et al., 1994; O'Loughlin, 1992). Examples include dividing 'acceleration' as the tangential and radial components ( $\bar{a} = \bar{a}_t + \bar{a}_r$ , #3, 6, 12, 13); discrimination between equilibrium as it relates to 'force' and "energy" (#3), and the flow of conceptual reasoning before mathematical manipulation (#9, 11, 12, 13).

Therefore, in order to acquire fluency in reasoning using Newton's first and second laws, students not only need to shift their naïve ideas about 'force' towards scientific ideas but also must gradually gain acquaintance with the meanings and functions of the invented scientific concepts, such as 'acceleration', 'tangential', and 'equilibrium', and comprehension of the subtle and implicit variations corresponding with different contexts of physics. Therefore, the teacher's role is not only to initiate 'anomalies' to facilitate conceptual change but also to provide intensive mediation regarding the associated scientific concepts (O'Loughlin, 1992), along with abundant examples for repeated practice (Airey & Linder, 2009; Chang, 2011).

Finally, 'equilibrium' may seem like a familiar, obvious, and simple idea in both physics and everyday life. However, this study clearly shows that the concept of equilibrium is much more profound and counter-intuitive than many students perceive. Likewise, there may be many more *apparently* simple terms that significantly confuse students and impede their fluency in physical reasoning. Being aware of the challenges is a first step towards enhanced teaching and learning.

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# 3 Primary school students' use of the concepts of evidence in science inquiries

*Winnie Wing Mui So, Liang Yu, and Yu Chen*

## Introduction

There has been a significant focus on science inquiry in science education in recent decades (Lederman et al., 2014). A number of reform documents (e.g., Education Bureau (Hong Kong), 2011; A Framework for K-12 Science Education, National Research Council [NRC], 2012; Next Generation Science Education [NGSS], 2013) explicitly state that students should develop the process skills necessary to undertake science inquiry and to become scientifically literate. For better scientific investigations, our students need not only “skill of” but also “knowledge about” inquiry (NRC, 2012).

Procedural knowledge refers to knowledge of the procedural aspects associated with conducting a science inquiry (Millar, Lubben, Gott, & Duggan, 1994; Peters, 2008). According to Roberts (2001), ideas about the collection, analysis, and interpretation of data and evidence have to be understood before our students can effectively interact with scientific evidence. Gott and Duggan (1995a, 1996) used the term ‘concepts of evidence’ to distinguish procedural knowledge from other conceptual or substantive knowledge, and argued that a lack of procedural knowledge might limit students’ demonstration of procedural practice. However, Roberts and Gott (2008) commented that there was still very little understanding of how ideas about evidence contribute to better experimental work. Additionally, these ideas may seem too difficult for students, and cannot be effectively taught by some teachers.

Therefore, the present study sought to investigate Hong Kong primary students’ use of seven aspects of the concepts of evidence in their science inquiries. It is hoped that the findings will contribute to our understanding of the difficulties primary students encounter in using these concepts of evidence when conducting science inquiries, and inform strategies for teachers to better foster students’ procedural knowledge (Yore & Hand, 2010). Analysis of students’ use of the concepts of evidence will also help to identify baseline data for primary students’ abilities to apply procedural knowledge in science inquiries.

## Concepts of evidence

Gott and Duggan (1995a) labeled the ideas about evidence as ‘concepts of evidence’ and regarded it as an integral part of science and a kind of knowledge



that can be learned, understood and applied, rather than a set of skills that are developed implicitly by scientific practices. They argued that there is a need for science education to teach not only the basic scientific facts but also the basic ideas about evidence. Through either explicit or implicit teaching, students are expected to develop an understanding of how science works, including that science develops based on the analysis and interpretation of scientific evidence (Gott & Roberts, 2004). As future scientifically literate citizens, students should be able to collect, analyze and explain scientific evidence and make considered decisions based on it (Kuhn, 1992; OECD, 2010; Osborne, Erduran, Simon, & Monk, 2001).

With reference to the previous studies, including Gott and Duggan (1995a), Gott, Duggan, and Ebrary (2003), Chin (2003), and Jeong, Songer, and Lee (2007), this study placed specific emphasis on students' use of the following seven aspects of the concepts of evidence. Note that these aspects mostly relate to a certain type of scientific method, that is, a fair test. Additionally, these aspects are required in the *Science Education – Key Learning Area Guide (Primary 1 – Secondary 3)* (The Curriculum Development Council (CDC), 2002). As stated in this guide, until primary 6, pupils are expected to be able to “collect data, decide how to represent them, and test the reliability of the knowledge they have generated” and “to make presentations to others and [be] willing to receive constructive criticism” (CDC, 2002, p. 88). In the study by Warwick, Stephenson, Webster, and Bourne (2003), they also applied the work of Gott and Duggan (1995a) as an analysing framework to test levels of pupils' use of concepts of evidence in their scientific reports, including not only the following seven aspects but also sample size and multivariate data. Hence, it is believed that the pupils could apply these seven aspects of the concepts of evidence in their scientific projects. More details of the seven aspects are presented as follows.

- a *Variable identification and types* – this entails understanding and identifying the independent variables, the dependent variables and the cause-and-effect relationships between them. The independent variable is the variable for which values are purposefully chosen by the investigators, while the dependent variable is the variable whose value is measured for each and every change in the independent variable.
- b *Fair tests and control variables* – if the impact of the independent variable on the dependent variable is to be measured, interference of the other relevant variables (control variables) should be eliminated. Valid data can be acquired only if fair tests are adopted and all the control variables are kept consistent.
- c *Choosing instruments* – the selection of appropriate instruments or tools for measurements helps to ensure validity. The following aspects should be taken into account when selecting an instrument for measurement: its accuracy and reliability, the measurement scope of the experiments, whether the instrument can be understood and operated, and whether it can generate

readable data. Moreover, attention should also be paid to the appropriate use of the instrument.

- d *Choosing values* – variables are comprised of categorical, ordinal, and continuous variables. Choosing the appropriate scale, interval, range and frequency of different types of variables is important for collecting valid data and for the preparation and reading of tables and graphs, from which the trends and patterns in the data can be identified.
- e *Repeatability of observation and measurement* – repeatability is also known as reliability. As errors or uncertainties may occur in the operation process of a single experiment, experiments may need to be repeated in order to obtain data with high reliability. In other words, the difference among the data derived from the repeated experiments should fall within an acceptable range.
- f *Data presentation with graphical representations* – graphical representations can present data to better explore the patterns of and the relationships between variables. Typically, pictures, photos, or illustrated drawings are used to present the experimental phenomena. Tables are used as organisers for an investigation or as tools for data collection and presentation. A table should include a title indicating the meaning of the table; names, units and values of the independent and dependent variables; and necessary explanations in the text. Graphs or charts can help to represent the range and interval of measurements and to display and report data after an experiment, making it easier to see patterns and trends.
- g *Interpretation of results* – this refers to appropriately interpreting, analysing, predicting and summarizing data, including identifying and interpreting the trends and patterns derived from the graphical representations.

## Science inquiry and the concepts of evidence

Science inquiry refers to “the characteristics of the processes through which scientific knowledge is developed” (Schwartz, 2004, p. 8). Internationally, reform documents have identified science inquiry as the diverse ways in which scientists explore the natural world and propose explanations based on scientific data and evidence (e.g., The National Academy of Science, 2002; NRC, 1996). As illustrated in the National Science Education Standards (NRC, 1996), scientific inquiry refers to “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work”, and is a multifaceted activity that involves “using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results” (NRC, 1996, p. 23).

Some researchers have introduced the notion of evidentiary competency to refer to the concepts and reasoning skills required to collect reliable, valid data and to organise and interpret the data so they can be used for evaluating theories and explanations (Jeong, Songer, & Lee, 2007). So and Zhong (2010) described

science inquiries as the processes that could consist of the three main stages of research design, measurements, and data handling, and regarded validity and reliability as being at the core of developing students' competences in science inquiry. Validity refers to whether the evidence really provides the answer to the question, while reliability refers to whether we can establish ways of having reliable measurements (Gott & Duggan, 2002). The validity and reliability of the scientific evidence determines the quality of the inquiry.

Primary school students are expected to develop specific inquiry skills and knowledge, such as choosing appropriate instruments, using instruments in correct ways, and repeating experiments (Gott & Duggan, 1995b). However, research has indicated that children have failed to develop meaningful understanding under science-as-process instructional programs (Duschl, Schweingruber, & Shouse, 2006). The procedural knowledge or the concepts of evidence focused on understanding at the cognitive or metacognitive level can hardly be enhanced by just repeated extensive practice. For instance, students are often asked to keep control variables consistent when conducting investigations, but they may not necessarily have an adequate conception of why they need to do so (Lederman et al., 2014). Gott and Roberts (2004) assessed the procedural understanding of pupils through a written test. A total of 96 pupils aged 14–15 years from a school in England participated in the test. The results revealed that many of the students had difficulties understanding the ideas of variable structure and validity, repeated experiments, and design validity. Few could use ideas of sample size and representativeness or draw conclusions consistent with counter-intuitive data.

## Methodology

The research presented in this chapter aimed to investigate Hong Kong primary students' application of procedural knowledge in their science inquiry projects. The specific research questions were:

- What are the concepts of evidence generally used by primary school students in their science inquiries?
- Which concepts of evidence do the primary school students apply more appropriately and meaningfully in their science inquiries?

### *Hong Kong's annual 'primary science inquiry' event*

The primary school science curriculum in Hong Kong was implemented in the early 1980s (So & Cheng, 2009). However, according to Education Commission Report No. 4 (1990), the numerous and loosely independent subjects of the primary school curriculum needed to be further integrated. Therefore, in 1996, the three subjects of science, health education, and social sciences were integrated into a new subject – general studies for primary schools. In

more recent curriculum reforms, general studies has been further developed to provide primary school students with a platform to integrate skills, knowledge and values across the three key learning areas of science education, technology education, and personal, social, and humanities education (Education Bureau, 2011).

In order to inspire primary students' interest in learning science, and to cultivate their attitudes and abilities to conduct careful observations and science inquiries in their daily lives, an annual event, 'Primary Science Inquiry', was initiated by several science education organisations to provide opportunities to foster primary students' curiosity and sensitivity to the world around them, and to improve their science inquiry skills and other high-level thinking skills such as problem solving, communication and collaboration, creative thinking, and critical thinking.

In its fourteenth event, a total of 115 teams from different primary schools in Hong Kong participated in the annual event of 'Primary Science Inquiries'. The participating students were mainly upper primary students aged from 10–12 years. They are required to conduct the science inquiry project in small groups of four to six members. It takes students about half a year to submit their inquiry design, carry out the inquiry activities, and complete their inquiry reports for presentation.

### *Data collection*

From the fourteenth Primary Science Inquiries event, after eliminating some reports with incomplete content that influenced the analysis, 30 well-structured reports (appropriately 26% of the 115 reports) were randomly selected, with 10 from each of the following award levels: outstanding, merit and consolation. The criteria of giving out these awards include: (1) the use of scientific inquiry (students are able to properly propose hypotheses and questions, collect and analyze data, conduct experiments, and draw conclusions); (2) the use of scientific ideas/principles (students are able to apply relevant scientific theories to achieve the purpose of inquiry); (3) creativity of the inquiry (there are originality and creativity in the procedure and product of inquiry); and (4) the practicality of the inquiry (the inquiry product can be applied in daily life) (So, 2014, p. 64). The 30 selected reports are listed in Appendix A.

### *Data analysis*

Qualitative content analysis (Kuckartz, 2014) was adopted to analyze the use of the seven concepts of evidence in these 30 science inquiry project reports. Figure 3.1 presents the analytical framework and shows that each aspect of the concepts of evidence contributes to the quality of the science inquiry.

Two independent raters were involved in the process of coding to guarantee its consistency so as to achieve a more reliable data analysis. The kappa coefficient (Cohen, 1960) was calculated to examine the agreement level between the two

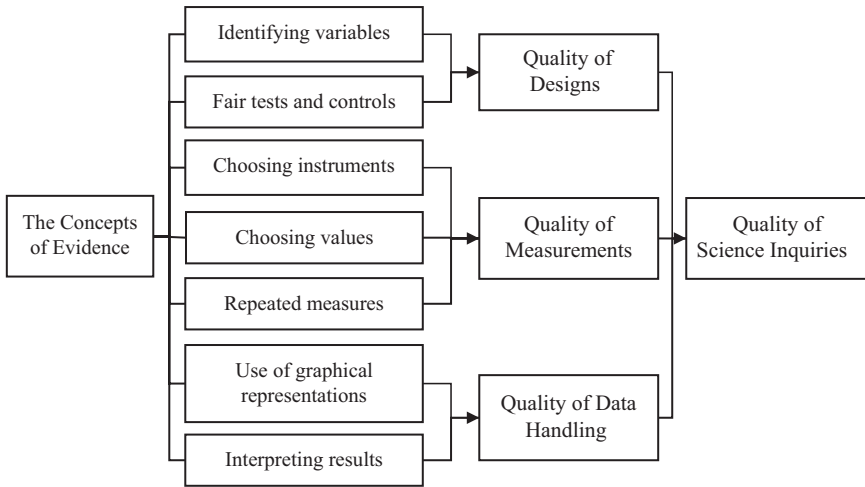


Figure 3.1 The analytical framework incorporating the concepts of evidence

raters. The kappa coefficient for the coding of the full sample ( $n = 30$ ) initially had a result of 0.655. After discussion and re-evaluation, the second test on the 30 samples had a kappa coefficient of 0.857, indicating acceptable inter-rater reliability.

## Results

The findings are presented in terms of two related aspects: (1) use of the concepts of evidence in science inquiry and (2) how well the concepts of evidence are used in science inquiry.

### *The use of concepts of evidence in science inquiry*

Table 3.1 shows a summary of the embeddedness of the seven aspects of the concepts of evidence in these project reports, but no judgment of how well each concept was applied. Generally, the students seemed to be able to apply the concepts of variable identification and variable types, fair tests, choosing instruments, and using graphical representations when conducting science inquiries: almost all of the projects involved the processes of identifying variables and types (94%), choosing instruments (90%) and using graphical representations (100%). However, fewer (69%) determined the values of variables (e.g., scale, interval, or range of variables); 62% showed evidence of conducting fair tests. The use of repeated measurements was found in 59% of the projects, and less than half (38%) included an interpretation of the results.

Table 3.1 The concepts of evidence embedded in the science inquiry projects (n = 30)

<i>The concepts of evidence</i>	<i>Occurrence in the science inquiries</i>	<i>Concept of evidence appropriately used</i>	<i>Concept of evidence inappropriately used</i>
<b>Quality of design</b>			
1 Identifying variables	28 (94 %)	14 (47 %)	14 (47 %)
2 Planning a fair test	27 (90 %)	16 (53 %)	11 (37 %)
<b>Quality of measurements</b>			
3 Choosing instruments	27 (90 %)	14 (47 %)	13 (43 %)
4 Choosing values	23 (77 %)	12 (40 %)	11 (37 %)
5 Repeating measurements	26 (87 %)	8 (27 %)	18 (60 %)
<b>Quality of data handling</b>			
6 Using graphical representations	30 (100 %)	11 (37 %)	19 (63 %)
7 Interpreting results	11 (37 %)	6 (20 %)	5 (17 %)

### *Quality of application of the concepts of evidence*

The following sections identify how appropriate use of the concepts of evidence contributed to the overall quality of the projects, and how inappropriate use affected the validity and reliability of the inquiries.

#### *Use of concepts of evidence in the inquiry design*

Most projects involved the identification of independent and dependent variables. Around half of the projects (47%) used continuous variables such as different weights, temperatures, time, or concentrations, whereas the others used categorical variables.

However, 47% of the projects did not correctly identify the independent and dependent variables according to the inquiry purposes or hypotheses. For instance, in Project A02, "Dissolved egg shell", several solutions, including cola, vinegar, lemon juice and water, were compared to determine which could dissolve the egg-shell faster. The students identified the pH value or  $H^+$  density of each solution as the independent variable. However, the independent variable should actually be whether the acid is stronger than carbonic acid (the main component of eggshell). For stronger acids, the higher the  $H^+$  density, the faster the dissolution rate. In project C05, "The magic liquid", the purpose was to investigate how ginger milk curd

can be more effectively made by mixing ginger juice and milk. However, in one of the experiments in this project, the students tested whether lemon juice (independent variable) can lead to the formation of milk curd, which was considered to be irrelevant to the purpose of their inquiry. The selection of the independent variable in this experiment was therefore inappropriate.

Identifying and monitoring controlled variables to isolate the effect of the independent variable on the dependent variable to achieve a fair test seemed to be difficult for the students. Of all of the projects, 37% did not adequately control the dependent variables, for example, the physical properties of the objects such as surface area, volume, mass, shape, location, and concentration; whether the manual operation was standardised, such as the control of strength or direction; whether the materials for the test interfered with each other; and factors related to the external environment. In projects C05, “The magic liquid”, and A09, “The use of vinegar”, independent and dependent variables were identified, but additional variables impacting the dependent variables were not controlled (e.g., temperature, density or volume). The students in these projects did not seem to be aware of the need to control other variables.

#### *Use of concepts of evidence in measurements*

Among the 30 projects, the most frequently used instruments were timers, rulers, electronic scales, pH test paper, thermometers, and hygrometers. Several projects developed their own instruments. For example, for project C04, “Making a Higher Coca-Cola Spring”, students designed their own instrument to calculate the volume of released CO<sub>2</sub>.

However, just less than half the projects (47%) showed appropriate selection and use of instruments for recording accurate measurements. For example, in project B05, “The most delicious chiffon cake”, conclusions were based on the personal views of six classmates after they tested four types of chiffon cake. The students did not realise that they needed to use statistical methods, such as asking the six students to give scores (1 to 4 represents “the worst” to “the best”) and then comparing the sum or average scores of each type of cake, so as to make the results or conclusions more objective. In project A01, “Endless fragrance of cheese”, students tested the protein quantity of the four types of cheese (solid) using proteinuria test papers, not realizing that this kind of paper can only be used to test the quantity of *liquid* protein.

Choosing appropriate variable values is also essential for recording and reporting measurements appropriately. Of the 23 projects that provided values, only 40% demonstrated appropriate selection and use of values for the variables, while 37% appeared not to have used values sufficiently sensitive for addressing their research questions or hypotheses (see Table 3.1). For instance, project A03, “Ginger milk curd”, explored the optimal coagulation temperature of ginger milk curd by observing changes in milk over time at 63.5°C, 65°C, 66°C to 72°C. However, the values of the temperature were too narrow to be able to identify the differences among the different experimental groups. Another typical

example is project A04, "Can the flashing light be turned off?", which tested the luminosity of a glow stick over temperatures from 0° C to 90° C with intervals of 5° C. Similarly, the values chosen were too narrow. Although such a design was useful for collecting adequate data, the process of data collection was very time consuming and some data collected appeared unnecessary. It is suggested that the students of A04 group could have chosen values from 0° C to 90° C with bigger intervals such as 10° C and then noted down whether the light could be turned off at each temperature.

Although the majority of the projects (over 85%) involved repeated measurements, the results of 18 projects (60%) were considered to demonstrate insufficient reliability (i.e., they did not use repeated tests, or they did not give a baseline for observations). Even among the 10 projects awarded as outstanding, only three generated evidence that we considered to be of better reliability by involving repeated tests as well as a baseline for observations. For instance, projects A01, A05, and A07 measured continuous variables, but did not use repeated tests to increase the reliability of the data collected. For some projects involving repeated testing, the students seemed unable to realise the need to set consistent standards for measurements. Hence, even though the tests were repeated, the data had relatively low test-retest reliability. Two typical cases are projects B01 "The King of the Cleaning Agent" and C02 "A Comparison of Cleaning Agents", both of which aimed to compare the effects of different types of detergents on cloth. The students invited a number of classmates to observe the phenomenon and then to provide scores on the effects of each detergent on cloth from five to one representing the most effective to the least effective. However, there was no baseline set for the observations, so the results could not be considered to be repeatable.

### *Use of concepts of evidence in data handling*

Among the set of 30 projects, a diverse range of graphical representations was used to present the inquiry results, such as pictures, photos, tables, and/or graphs. Of these, students appeared to be more capable of using pictures, photos, or images, but had some difficulties using tables and graphs appropriately.

Almost all of the projects used photos or images instead of words when presenting their results. Students seemed to regard images or photos as the most effective ways to record and report the results of their experiments. However, 11 projects (37%) were considered to lack several necessary photos as evidence, while 8 (27%) needed to improve the quality of their photos, as some were blurred and some were presented without explanatory titles. There were several factors, including the shooting position, angle, and distance, the experimental configuration, environmental conditions as well as other factors when taking pictures, which affected the trustworthiness and completeness of the photos and in some cases indicated flaws in the experimental design.

Tables were commonly used as the tools for collecting and presenting data. Only Project B10 did not provide the necessary tables. Of the others, one main



issue was that they lacked titles or explanations of scientific terminology and signs. These issues were evident in 13 projects (43%). Another issue was that they limited the use of tables to data presentation, but rarely used tables as ways of organizing the design in advance of the whole inquiry. As evident in these project reports, the use of tables was mostly found in the results section. Relatively few projects used graphs for the representation of findings, with only four (13%) incorporating bar charts, line graphs, or pie graphs.

After presenting their data, it was not common for the students to provide an appropriate interpretation of the results. They appeared to have difficulties analysing the underpinning patterns or relationships between variables, even with the use of graphical representations. The majority of the projects provided conclusions instead of interpretations. It was found that fewer than 40% of the projects included reasons why the particular results were obtained. For instance, Project C01, “The natural preservative”, did not provide a reasonable explanation for how sugar could act as a preservative (i.e., kill bacteria) under particular conditions. Moreover, among those projects that provided reasons (37%), only six (20% of the total sample) gave appropriate explanations. For example, in project B10, “The apple ripener”, there was an outlying data point that contradicted the other results. While the students attempted to explain why such an unexpected outcome could have occurred, the explanations were unclear and illogical.

## **Discussion and conclusions**

This study examined Hong Kong primary school students’ use of the seven aspects of the concepts of evidence in science inquiries through analysing 30 project reports selected from the fourteenth Primary Science Inquiry event.

### *Main difficulties in using the concepts of evidence during science inquiry*

Without knowing how evidence can be collected and interpreted, it is not possible to conceive of or carry out a science inquiry of high quality (Roberts, Gott, & Glaesser, 2010). This study revealed that the application of the concepts including “choosing values” and “interpreting results” would be more challenging for the students since these two concepts were least embedded in the students’ projects. For the concepts including “identifying variables”, “repeated measurements” and “use of graphic representations”, it was found that more than half of the students applied these concepts in incorrect or inappropriate ways. Therefore, science education should aim to develop students’ comprehensive procedural understanding, and in particular, better understanding of the earlier concepts of evidence, and to include the teaching of procedural ideas as an explicit part of the curriculum. This is consistent with many current curricula. For example, the *Framework for K–12 Science Education* (NRC, 2012) requires that primary students learn about collecting categorical

or numerical data for presentation in forms that facilitate interpretation, such as tables and graphs. When feasible, computers and other digital tools should be introduced to enable this practice.

*The relationships between the concepts of evidence and science inquiry*

The lack of procedural understanding is likely to hinder students' adoption of appropriate scientific methods. In other words, the understanding of evidence is essential for primary school students who aim to design and conduct science inquiries with sufficient precision. Understandings of the concepts of evidence, as identified in this paper, ostensibly also contribute to students' ability to interpret and critique scientific evidence and therefore their general scientific literacy.

Figure 3.2 brings together our current understanding of the connections between the concepts of evidence and the quality of science inquiries (Figure 3.2). From this figure, it is evident that the quality of a science inquiry relates to the appropriate use of all seven concepts of evidence. Put another way, to ensure the validity and reliability of a science inquiry, careful consideration is needed of each of the different concepts of evidence across the stages of research design, measurement, and data handling. In the research design stage, efforts should be taken to appropriately identify the independent and dependent variables. It is also necessary to consider how to keep all other variables consistent so as to meet the requirements of a fair test. At the measurement stage, one needs to choose sufficiently sensitive instruments and values, and repeat the experiment a sufficient number of times to ensure reliability. The third stage, data handling,

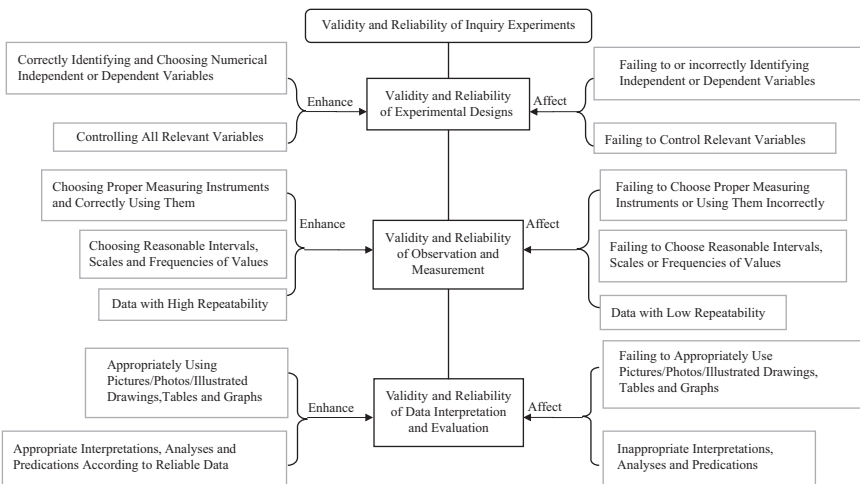


Figure 3.2 Relationships between the concepts of evidence and the validity and reliability of inquiry experiments

requires appropriate data presentation and interpretation. The appropriate use of pictures, photos, illustrated drawings, tables and/or graphs is the core component of thoughtful result presentation and interpretation.

### *Promoting primary students' understanding of the concepts of evidence*

It seems from the findings in this study that additional efforts are needed to promote the understanding of the concepts of evidence among primary school students in Hong Kong. As shown in this study, the students' procedural knowledge seemed to impact on the quality of their inquiry projects, especially on the choice of variables to be measured and controlled and the choice and use of measuring instruments. This finding is consistent with Gott and Duggan (2002). Hence, facilitating students' procedural knowledge is important for supporting their science inquiries.

Several scholars have suggested using an explicit teaching approach to include procedural ideas in the classroom (Roberts et al., 2010; Schalk, van der Schee, & Boersma, 2013; Warwick et al., 2003), arguing that students need opportunities to explicitly reflect on the quality of their own investigations and to apply what they understand about evidence in more than one context. Roberts et al. (2010) revealed that explicit teaching contributed to greater improvement in students' sophisticated understanding and conducting of valid and reliable science inquiries, and suggested that procedural knowledge was possible and necessary to be incorporated into the school curriculum at all ages. As such, it is suggested that teachers provide explicit teaching on the status and use of concepts of evidence by integrating them into inquiry activities, and require students to reflect on and develop their procedural knowledge and understanding (Gott & Roberts, 2004).

However, for teachers to implement such explicit teaching, it is important that they develop adequate procedural knowledge and related pedagogical skills (Khaparde, Paosawatyanong, & Wattanakasiwich, 2010; So, 2016). This study summarises the connections between the concepts of evidence and the scientific inquiry process in Figure 3.2, which can be used to facilitate teachers' personal procedural knowledge as well as relevant pedagogical skills. For instance, teachers can learn about how the seven aspects of the concepts of evidence impact the quality of the scientific inquiry as demonstrated in Figure 3.2. Teachers can also use it as a pedagogical framework to support their students' learning about evidence, starting with explicitly asking students questions about the use of the concepts of evidence in science inquiries, and then encouraging them to carefully think about why the use of the concepts of evidence leads to high quality investigations.

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# Appendix A

## Identifying codes of the 30 selected science inquiry projects

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<i>Awards</i>	<i>Codes of the science inquiry projects</i>
Outstanding Award	A01 “Endless Fragrance of Cheese” A02 “Dissolved Egg Shell” A03 “Ginger Milk Curd” A04 “Can the Flashing Light Be Turned Off?” A05 “Which Kind of Material Can Make the Glue the Stickiest?” A06 “Solving the Riddle of Why the Pocket Warmer Can Give out Heat” A07 “Candy Change, Change, Change!” A08 “Waste Oil Changes – Tests of the Effects of Various Waste Oil Soaps” A09 “The Magical Effect of Vinegar” A10 “The Impacts of Connection Fluid on the Environment”
Merit Award	B01 “The King of the Cleaning Agent” B02 “Hygroscopic Agents in Everyday Life” B03 “Can Mouthwash Damage Oral Cells?” B04 “The Secret Recipe of the Magic Bubbles” B05 “The Most Delicious Chiffon Cake” B06 “Dehumidifier – Natural vs. Artificial” B07 “How to Make the Sliced Fruit Not Get “Rotten”” B08 “A Comparison of Vitamin C” B09 “Inquiry into the Various Anti-oxidation Effects of Teas” B10 “The Apple Ripener”
Consolation Award	C01 “The Natural Preservative” C02 “A Comparison of Cleaning Agents” C03 “When Fruits Meet Salt” C04 “How to Make a Cola Fountain Spray Higher” C05 “The Magic Liquid” C06 “The Discovery of Soap” C07 “How to Make the Apple Flesh “Rot” More Slowly” C08 “Why Does My Bike Get Rusty?” C09 “A Good Way to Eliminate the Smell of Urine” C10 “The Mystery of Why Lemon Has to be Separated from Milk”

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# 4 Understanding students' co-construction processes of scientific modelling in Korean junior high school classrooms

*Chan-Jong Kim, Min-Suk Kim, Hyun Seok Oh, Jeong A Lee, and Seung-Urn Choe*

## Introduction

In the past half-century, historians and philosophers of science have perceived the centrality of models in scientific research (Bailer-Jones, 2009) and have devoted considerable time to documenting and understanding the role of models in science (Matthews, 2007). Models can show how theories contribute to modelling specific phenomena, provide insights and contribute to our understanding of the natural world, and simplify and try to capture the essence of things (Bailer-Jones, 2009). Moreover, modelling plays a central role in scientific inquiry (Passmore, Stewart, & Cartier, 2009).

The value and potential of modelling in science classrooms has been emphasised by many researchers (Passmore et al., 2009; Windschitl, Thompson, & Braaten, 2008). Model-based inquiry has been regarded as one way to address the limitations of skills-based, procedure-oriented inquiry (Baek & Schwarz, 2015). Louca and Zacharia (2012), reviewing a substantial number of studies related to model-based learning, summarised them into five categories: cognitive, metacognitive, social, material, and epistemological. Despite the importance of model-based learning, relatively little is understood about how students learn through model-based learning.

This study aimed to design and develop a model-based learning approach and sequence, and to understand the learning processes of students participating cognitively and socially in model-based learning activities. In this study, co-construction of scientific models (CCSM) is used to describe modelling within a community of practice (Lave & Wenger, 1991) or collective social practice (Fleer, 2015) in science classrooms.

## Conceptual underpinning

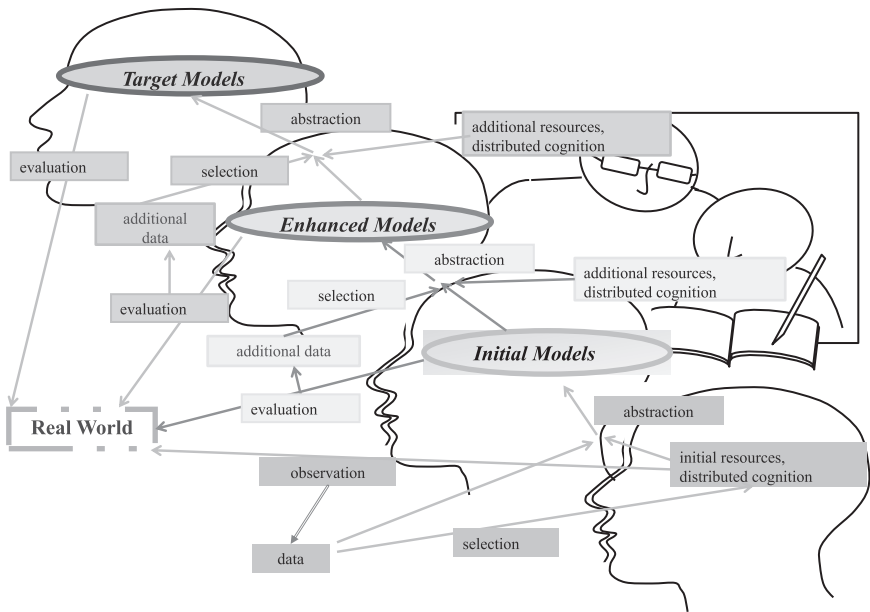
In this section, scientific models and modelling processes are outlined. To describe social interactions, the concepts of situation definition (Wertsch, 1984) and intersubjectivity are introduced.

*Scientific models and modelling*

Scientists engage in knowledge building and the development of coherent and comprehensive explanations through developing and testing models (Windschitl et al., 2008). The model itself is a set of hypothesised relationships among objects, processes, and events. Generally, models are synthesised to form scientific theories (Giere, 1988). For example, plate tectonics consists of a set of models, including sea-floor spreading, plume tectonics, tectonic plates, and plate boundaries.

Modelling processes are known to involve the evolution of models (Clement, 2008): from initial, to intermediate, and then to target models. To construct models, scientists and students construct explanations using data from observations and resources available for their inquiry. Nersessian (2008) delineated the model-based reasoning processes of scientists using a historical exemplar: Maxwell's field equations for electromagnetic phenomena. She referred to the ways of explanation construction as abstraction processes. Analogy, simulation, imagistic reasoning, and limiting case analysis are examples. Clement (2008) also reported experts' and students' use of imagery, analogy, and mental simulation during model construction processes in many domains of science.

The illustration of modelling processes in classrooms in Figure 4.1 shows the students' cycles of modelling, from constructing initial models through



Co-Construction of Scientific Models (CCSM) in classes

Figure 4.1 Simplified modelling process during CCSM in classes



enhanced models to target models. In the first cycle, resources initially available and data gained by observation form the basis of the abstraction processes. As modelling involves social practice, distributed cognition also plays an important role. Models developed in each cycle are evaluated for whether they can explain patterns in the data, can correctly predict the results of new observations, and are consistent with other ideas (Cartier, Rudolph, & Stewart, 2001). Teachers can facilitate students' modelling by providing additional relevant resources and perspectives. In the second and third cycle of modelling, students modify or improve their initial models based on the results of model evaluation and additional data from observation or information from teachers. Students may experience more than one cycle of constructing enhanced models. As they develop models together, with the teacher's guidance, we refer to this approach as CCSM. Using this diagram as a framework, CCSM processes involve three levels: what models are developed (the macrolevel), what abstraction processes are used (the mesolevel), and what kinds of resources are available and used for abstraction (the microlevel).

### *Situation definition and intersubjectivity*

To understand the CCSM practice, researchers need to identify and describe students' interpretations of the situation and progress of ideas. As CCSM is a social practice, understanding the ways in which ideas are introduced, interpreted, shared, and agreed is crucial. The concepts of situation definition and intersubjectivity are used for this purpose.

### *Situation Definition (SD)*

The concept of situation definition (SD) was first proposed and defined as the representation of purpose (situation) that is recognised by participants (Wertsch, 1984). Park and Moro (2006) enriched the definition to include participants' interpretations of physical space, role, status, task, and specific objects in interactive situations. However, both definitions were developed in the context of young children's simple tasks with little content. As CCSM usually involves tasks with rich content and complicated aspects, a more elaborate version of SD is necessary. Schuh, Kuo, and Knupp (2013) proposed a more advanced definition: "a learner's SD is his/her prior learning in action, reflecting personal characteristics of the learner and how the individual views the new learning opportunities" (p. 3). It includes content by relating prior learning in action, as well as views and personal characteristics. However, this definition still needs to be elaborated to describe the complex and multi-level aspects of CCSM processes. Through reviewing the data collected in this study, researchers realised that solving tasks involves very complicated components at different levels. Each participant's understanding of the task as a whole, the output constructed, the activity participated in, the material dealt with, and the ideas introduced all need to be documented. The researchers developed a multi-level framework (see data analysis

section) for describing SD with two main levels: SD for the task as a whole and SD for modelling processes.

### *Intersubjectivity*

The concept of intersubjectivity has been used widely and with various meanings. Gillespie and Cornish (2010, p. 19) categorised these concepts using six definitions: agreement in the sense of having a shared definition of an object; mutual awareness of agreement or disagreement; attribution of intentionality, feelings, and beliefs to others; behavioural orientations towards others; the situated, interactional, and performative nature of intersubjectivity; and the partially shared and largely taken-for-granted background in which things can be said and done.

The process of achieving intersubjectivity has been described as occurring in three phases: beginning, intermediate, and end (Rommetveit, 1985). The beginning phase describes the common backgrounds and preconceptions participants have when first engaging in a joint task. The intermediate phase denotes the creation of a common ground of engagement among the participants involved in the joint activity. In this phase, participants' SD, mutual understandings, and perspectives play an important role by creating understanding of the task. The end phase refers to common outcomes and what has been learned by participants from engaging in the joint activity (Matusov, 1996). In this study, the beginning phase is characterised by the resources students bring into the classroom when they engage in CCSM: prior knowledge, cultural practices, and artifacts held in common. The intermediate phase refers to the process of using these pre-existing resources for the purpose of "creating a common ground among the participants in CCSM" (Matusov, 1996, p. 29). The end phase refers to agreement reached by all participants during CCSM. According to Rommetveit (1985), intersubjectivity among students is achieved through reciprocal processes of understanding the perspective of the other and through a process of 'negotiating' shared meanings. In this study, SD is understood as an individual's interpretation of the task, and intersubjectivity as the agreement among students about ideas in three phases.

### **Context of the study**

Korea has a 6-3-3-4 educational system and a national curriculum that serves as the basis for educational content at each school and for textbook development. This study was conducted in a science class for students in their second year of junior high school where science is introduced as integrated science with four fields of study: motion and energy, material, life, and Earth and space. The Korean National Science Curriculum aims to help students understand basic concepts of science through inquiry about natural phenomena and objects and by developing scientific thinking skills and creative problem-solving abilities (Ministry of Education, 2006).

The major goals of this study were to develop CCSM strategies and teaching sequences with classroom teachers, and to understand CCSM processes about annual parallax. Annual parallax is the semi-angle of inclination between two sight lines to a star, as observed when the Earth is on opposite sides of the sun in its orbit. It is used to measure the distance between stars.

Drawing on an extensive literature review and collaborative discussion among researchers and participating teachers, a CCSM teaching strategy was developed (see Figure 4.2) consisting of four phases: exploration, small-group modelling, whole-class modelling, and model deployment. In the exploration phase, students participate in data collection, interpretation and individual modelling activities. During small-group and whole-class modelling, students generate, evaluate, and modify models developed through discussion. Teachers facilitate students' modelling and model development by monitoring progress, providing additional resources and perspectives, and suggesting constraints when appropriate. Constraints provide key information for constructing, evaluating, or modifying models, and help frame a problem by imposing a condition on its solution (Kim, 2015).

Based on the CCSM strategy, a sequence for teaching about annual parallax was developed with participating teachers and researchers (see Figure 4.3). Before the CCSM lessons, students received 10 class hours of instruction focused on learning about the solar system and the universe, including constellations,

[Exploration]	[Small-Group Modelling]	[Whole-Class Modelling]	[Model Development]
Data collection and interpretation	Model Generation Evaluation Modification	Model Presentation Evaluation Modification	Apply models to new situations
<Phase 1>	<Phase 2>	<Phase 3>	<Phase 4>

*Figure 4.2* CCSM teaching strategy

<i>[First lesson]</i>			
Review of previous lesson	Introduction of the task	Individual and small-group modelling	
<i>[Break time]</i>			
<i>[Second lesson]</i>			
Representing model	Exchange of group members	Presentation of models	Development of model

*Figure 4.3* CCSM teaching sequence for annual parallax

planispheres, the 3-D Big Dipper model, and parallax. The learning objective of the CCSM lesson was to be able to explain how to measure the distance between close stars using annual parallax. Data were collected during two consecutive 45-minute classes. In the first class, previous material was reviewed, the task was introduced, and students engaged in individual and small-group modelling. In the next class, the students worked in small groups to generate models to represent their ideas and then compared the models with other small groups before engaging in whole-class discussion about each model (Kim, 2013).

## Participants and tasks

This study took place in an alternative junior high school near Seoul that follows the national curriculum, uses textbooks approved by the government, and has smaller than average class sizes. The school places an emphasis on student-centred learning, and regularly employs cooperative learning approaches in all subjects. Twenty-three eighth-grade students (11 male; 12 female), with socioeconomic status higher than the national average, participated in this study. Four students were assigned to six even-gender, mixed-ability groups, with the exception of one group with only three students (one male; two female). All groups were tasked with learning about annual parallax (Figure 4.4). A veteran teacher of 17 years, with a bachelor's degree and grades 7–12 teaching certification in Earth science, participated in this study. He served as chairperson of a teachers' cooperative learning group, and regularly provided in-service teacher training about cooperative learning, a strategy he had used for many years.

*Task: The following pictures show the movement of Star A as seen from the Earth over a six-month period.*



- 1) *Why did Star A move?*
- 2) *Draw the relative position or movement of the Sun, the Earth, Star A and other stars that result the movement of Star A.*

*Figure 4.4* Task: learning about annual parallax

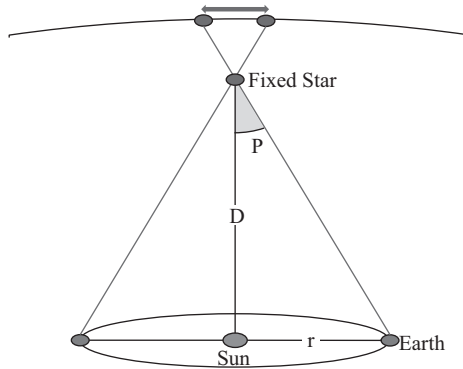


Figure 4.5 Target model for the task (annual parallax)

The target model of the lesson was annual parallax (Figure 4.5). Students were expected to explain the movement of Star A based on the revolution of the Earth and the distance to Star A.

### Data collection and analysis

Two camcorders recorded the lessons from different angles, and the interactions of each group were recorded with hand-held cameras and voice recorders. All recordings were transcribed and analysed. Members from three groups (12 students) were selected for analysis and participated in follow-up interviews. The other three groups were excluded from the analysis. One was excluded because one member already knew the target model, and the other two were excluded because they copied the models generated by other groups during break time rather than generating their own models.

### Data analysis

The CCSM activities of each group were divided into a series of episodes according to major themes or events. An analytical framework was developed at three levels (macro, meso, and micro) to reflect the CCSM process. We identified and described the initial model development at the macrolevel. At the mesolevel, model generation, evaluation, and modification (GEM) processes were identified and described. Finally, at the microlevel, we identified and described resources, data, behaviour, and beliefs used for GEM processes.

In model generation processes (mesolevel), simulations, analogies, and other abstraction processes were identified and coded as As, Aa, and Ao. For model evaluation, we focused on the criteria according to which the participants made evaluations. Data, predictions, and methods were formed using our analytical categories. Codes Ep, Em, and Ed were used for evaluation by prediction,

Table 4.1 A framework to describe SD

<i>Episode</i>	<i>Task</i>	<i>Macro</i>			<i>Meso</i>		<i>Micro</i>	
	<i>on off</i>	<i>Initial models (Mi)</i>	<i>Enhanced models (Me)</i>	<i>Target models (Mt)</i>	<i>Gener- ation (G)</i>	<i>Evaluation (E)</i>	<i>Modifi- cation (M)</i>	<i>Knowledge (K) Data (D)</i>

*Notes:* On task: students' interpretation of the task is compatible with the goal of the task. Off task: students' interpretation of the task is not compatible of the goal of the task.

methods, and data. Modifications were identified as small changes made based on evaluations. In all cases, serial numbers were placed after each code according to its order of occurrence. As part of our microlevel analyses, we identified and described when participants brought resources, including knowledge (coded as K) from their prior experiences and learning or when they used data (coded as D) attained from the task to generate models at the mesolevel.

To understand the group interactions, SD and agreement (intersubjectivity) were analysed and used to explain the development of ideas among the students in small groups. SD was understood as having two main levels. In the first, students' views about and approaches to tasks were identified and grouped as 'on task' and 'off task'. The second level was related to students' interpretations of the task, including resource and data selection and model construction. The SD of this level was identified at the macro-, meso-, and microlevels. The resulting analytical framework is provided in Table 4.1. Ideas and the students who suggested them are placed in the cells. Intersubjectivity, or agreement among students in small groups, was identified when they shared the same SD.

## Findings

The CCSM processes for the annual parallax task for three small groups were analysed. While each group showed unique processes, two showed similar processes. To better understand the CCSM processes, we focus on describing the model generation process at the macro, meso, and microlevels for these two groups.

### Group 1

CCSM processes consisted of 15 distinct episodes: (1) beginning, (2) table tennis ball distraction, (3) parallax, (4) teacher's first visit, (5) Earth's revolution, (6) illusion, (7) expressing a model, (8) model revision by the teacher, (9) turning, (10) end of first lesson, (11) teacher's third visit, (12) path, (13) board-marker distraction, (14) revolution rediscovered, and (15) summary of activity.

Each student began by sharing independently generated models from a prior lesson, which we call Earth's rotation (Mi1), Earth's revolution (Mi2), and God's creation (Mi3). Because the students' ideas were vague, models Mi1 and Mi2 persisted throughout the first four episodes of student negotiation. During

Table 4.2 Macro-, meso-, and microlevel analysis for small group 1's CCSM

Macro	Initial models (Mi)			Enhanced models (Me)			Ad hoc models (Mah)	
	Mi1	Mi2	Mi3	Me1	Me2	Me3	Mah1	Mah2
	Generation (G)			As2 As4 As1	Ao1 As3	As2-1	D3	
Meso	Evaluation (E)	D3			Ed3	Ed3 Ep1		Ed3 Ep1
	Modification (M)							
	Resource (K)	K1	K2	Br	K3 K6	K1 K4	K7	
Micro	Data (D)	D3			D2			

*Notes:* Mi1: Star A moved because of Earth's rotation; Mi2: Star A moved because of Earth's revolution; Mi3: Star A moved because God creates this way; Me1: Star A moved because of Earth revolution and visual illusion; Me2: hybrid model of Mi1 and Mi2, combining Earth's revolution and diurnal motion of stars at the same time; Me3: hybrid model of Mi1 and Mi2, consider Earth's revolution and path of stars with vertical orbits; Mah1: A similar star with Star A exists in the symmetrical position; Mah2: Star A moved because of strong gravity pull; As: simulation by illusion and K2; As2: simulation by E revolution (mostly using ping pong ball); As2-1: simulation by E revolution, vertically; As3: simulation according to hybrid model; As4: simulation according to distance to Star A; Ao1: hybrid model construction by combining Mi1 and Mi2; Ed3: evaluation using data D3; Ep1: evaluation by prediction; K1: stars move around Polaris; K2: (Earth) moves around the sun; K3: Earth moves around the sun (using the term rotation); K4: Earth revolution; K6: visual illusion; K7: path of stars; Br: God created it this way; D2: (Star A moved) six month ~ one year; D3: only Star A moved.

Episodes 1-4, members rejected the religion-based explanation Mi3 without explicit reason, and because they failed to distinguish between Mi1 (Earth's rotation/spinning) and Mi2 (Earth's revolution), they had difficulty reaching agreement. In Episode 6, an enhanced model (Me1) was developed by using an optical illusion to explain the movement of Star A by looking at the star from different positions in the Earth's orbit. In subsequent episodes, the students integrated Mi1 with Mi2 to develop Me2, a hybrid model. In Episode 12, the students suggested Me3 as a way to explain the vertical path of stars in relation to the Earth's orbit. However, because they failed to agree, two additional models, Mah1 and Mah2, were proposed and later rejected. Mah1 explained the movement of Star A by suggesting that a star similar to Star A exists in a symmetrical position. Mah2 explained that the movement of Star A was caused by a strong gravity pull (Table 4.2).

From the mesolevel analysis, we noted that simulation, analogy, and hybridisation were employed (Table 4.2). Five simulations were reported from the Group 1 dialogues. All simulations were executed to test ideas suggested by the students. Simulations were related to the Earth's revolution (As1, As2, and As2-1), a hybrid model (As3), and distance to Star A (As4). The students tested a parallax analogy (Aa4) by looking at Star A from different positions in the Earth's orbit, and tested

a hybrid model (Me2) through simulations (As3) with table tennis balls. Combining their two initial models (Ao1), Mi1 and Mi2, to develop an enhanced model is an abstraction process that has rarely been reported. Two types of simulations were observed: mental simulation (e.g., As1) and mental simulation with physical objects, such as table tennis balls (e.g., As2). Simulation with physical objects not only assisted the participants to process their ideas but also provided a common focus point for discussion. While other ad hoc models, including a symmetrical star (Mah1) and gravitational force (Mah2), were suggested, they were easily rejected because the students acknowledged that a similar star does not exist in the opposite position (Mah1), and predictions of a gravitation model lacked consistency (Mah2). The evaluation of ad hoc models showed that the students were able to evaluate their own models based on internal consistency (Mah1) and predictions with their own models (Mah2).

*Student A:* I do not know why only Star A moved.

*Student D:* It's because it gets strong gravitation.

*Student A:* That's when a star is light. In that case, all light stars should move. Heavy ones never move. That's not the case.

At the microlevel, various kinds of knowledge and information (data) from the task were used during modelling. Ideas from previous lessons, especially the Earth's rotation and the diurnal motion of stars (K1 and K7) were frequently used. However, knowledge related to the Earth's rotation was not relevant for this task, and prevented participants from developing target models. Data used during Group 1's modelling were related to the movement of Star A: period of movement (D2) and movement (D3). Sometimes data played important roles in the evaluation. For example, Student D critiqued Mi1 using Data 2 in Episode 1 (Table 4.2) and Student C argued against Me2 based on Data 3 in Episode 7. In the evaluation of the models, information gained from the task played important roles. For Group 1, evaluation based on D3, showing "only Star A moved," played critical roles in evaluating an enhanced model (Me2) and an ad hoc model (Mah2). It showed that D3 was the most important constraint for Group 1.

In summary, Group 1 began with multiple initial models. The Earth's revolution model might have been developed into the target model, as Me1 was closest to the target model. While the teacher tried to help with specific guidance, he failed to value and challenge students' resources (ideas); instead, he adopted authoritative strategies by repeating the scientific position focusing on the Earth's revolution.

## [Episode 11]

*Teacher:* This group did not figure out why only Star A moved? [Drawing]. The Earth revolves like this [clockwise], right?

*Student A:* Yes



- Teacher:* Stars are here, but why does only Star A move back and forth?  
That's . . . related to which aspect of the Earth?
- Student D:* The boundary – no, no, path, the path
- Student A:* Revolution
- Teacher:* [Drawing the Earth and its orbit] Revolution, revolution, if it revolves, then it is like this.
- Student D:* Because of the difference of the path?
- Teacher:* The path is different?
- Student A:* Ah! [Clapping] I see! [drawing symbols of Earth on opposite positions on its orbit]
- Student D:* Is he right? [Commenting on Student A's idea, revolution.]
- T:* [To this group] All right. Keep discussing that [issue] together [leaving the group].

As seen in Episode 11, during the teacher's third visit he tried to get the students to focus on the Earth's revolution. When Student D proposed paths for the stars, the teacher did not pick up and challenge this idea so the students did not focus on the teacher's suggestion about the importance of the Earth's revolution. Instead, they continued to focus on the paths of the stars, and as a result, failed to develop the target model. To understand the model developments among the students in Group 1, a summary of the students' models and abstraction activities is provided in Table 4.3. At a general level of SD, the students showed on-task behaviour; however, some of them were distracted in several episodes (2, 3, 5, 13, 14, and 15) by materials provided by the teacher for the activity, such as table tennis balls, a small white board, or markers. At a more specific level of SD, the students showed different SDs at different (macro, meso, and micro) levels (Table 4.3).

In terms of intersubjectivity, the three initial models (Mi1, Mi2, and Mi3) represented three different SDs at the macrolevel. While Student B strongly held to Mi3 (God's creation), Students A and D, and later Student C, shared a similar SD (Mi2 and/or Me1). Students A, C, and D shared knowledge of the Earth's revolution (K4) and optical illusion (K6). Connections between these models were during simulations about the Earth's revolution (As2), which led to an Earth's revolution-based model (Mi2) or Me1. At the same time, Students A and D introduced their shared prior learning about the Earth's rotation (K1) and the diurnal motion of stars (K7), which seemed to lead them to develop hybrid models (Me2 and Me3). They also shared and used K1 (stars move around Polaris) in Episodes 7 and 8 and K7 in Episodes 6 and 11, which supported their abstractions As2-1 and As3, thus ending up with a hybrid model (Table 4.3).

## ***Group 2***

The CCSM processes consisted of eight episodes: (1) Beginning, (2) Distance to stars, (3) Discussion about the movement of Star A, (4) Target model, (5) Deployment of model to the Big Dipper, (6) Target model, (7) Giving up the Big Dipper application, and (8) Completing the expressed model.

Table 4.3 Students' models and abstraction activities of small group 1 across episodes

Episode	Task		Macro			Meso			Micro	
	on	off	Initial models (Mi)	Enhanced models (Me)	Ad hoc models (Mah)	Generation (G)	Evaluation (E)	Modification (M)	Knowledge (K)	Data (D)
1	all	-	Mi1(A) -Mi1(D) Mi2(D) Mi3(B) -Mi3(AC)			As2(A) As2(A)	Ed2(D)			
2	A,B,D	A,B,C	Mi3(B)	Mi3(B)		As2(A)			Q(B) K4(C)	
3	A,B	C,D	Mi2(A)			As2(A)				
4	all		Mi1(C) Mi3(B)							
5	all	B	Mi3(B)						K4(ACD)	
6	all	-		Me1(AD)		As2(AD), As4(AD)	As1(D)		K6(ACD), K7(AD), K1(D)	
7	all		Mi2(CD)	Me2(AD) -Me2(C)		As2(C), Ao1(AD)	As3(AD) Ed3(C)		K1(AD)	
8	all								K1(D), K2(C)	
9	all					As2(AD),	As2-1(D)			D3(C) K1-1(D), -K1-1(A)
10	all			Mah1(B) -Mah1(ABD)						

(Continued)

Table 4.3 (Continued)

Episode	Task		Macro		Meso		Micro			
	on	off	Initial models (Mi)	Enhanced models (Me)	Ad hoc models (Mah)	Generation (G)	Evaluation (E)	Modification (M)	Knowledge (K)	Data (D)
11	all								K4(A), K7(D)	D3(C)
12	all			Me3(D) -Me3(C)		As2-1(D)		Ep1(C)		
13	C,D	A,B							DsA(D)	Ds(D),
14	A,C,D	B				As2(A)			K8(A), Q(C)	
15	A,C,D	B		Mah2(D) -Mah2(A)				Ep1(A)	K1(D)	D3(A)

Notes: A, B, C, D: students in the small group 1; Mi1: Star A moved because of Earth's rotation; Mi2: Star A moved because of Earth's revolution; Mi3: Star A moved because God creates in that way; Me1: Star A moved because of Earth revolution and visual illusion; Me2: hybrid model of Mi1 and Mi2, combining Earth's revolution and diurnal motion of stars at the same time; Me3: hybrid model of Mi1 and Mi2, consider Earth's revolution and path of stars with vertical orbits; Mah1: A similar star with Star A exists in the symmetrical position; Mah2: Star A moved because of strong gravity pull; As1: simulation by illusion and K2; As2: simulation by E revolution (mostly using the ping pong balls); As2-1: simulation by E revolution, vertically; As3: simulation according to hybrid model; As4: simulation according to distance to Star A; Ao1: hybrid model construction by combining other ideas into initial models; Ed2: evaluation using data D2; Ed3: evaluation using data D3; Ep1: evaluation by prediction; K1: stars move around Polaris; K1-1: stars move with the Earth; K2: (Earth) moves around the sun; K3: Earth moves around the sun (using the term rotation); K4: Earth revolution; K5: Earth rotation; K6: visual illusion; K7: path of stars; K8: parallax; Br: God created it that way; Data: D1: camera angle is related; D2: (Star A moved) 6 month~ 1 year; D3: only Star A moved; Ds: drawing stars; DsA: drawing Star A; Q: questioning; Underline: first group member who proposed the idea or expressed the position; -: rejection.

The Group 2 members suggested two initial models, Earth's revolution (Mi2) and Earth's rotation. In Episode 1, the students mistakenly employed the term *rotation* to mean *revolution* (Mi2-1), but this argument was abandoned when Student K insisted they focus on "why Star A moved" rather than their initial models. During Episode 2, the students realised Star A's distance from the Earth was relevant to their explanation. As a result, they developed an enhanced model (Me) with two analogies. The first analogy involved the telescope finder (Aa2), in which the students focused on the differences in the movement of stars as seen by a telescope with different powers of magnification. From this, they developed a target model (Mt) simulated with table tennis balls (As2) from which they could show Star A's movement to be an optical illusion. A unique component of this group's CCSM process was the use of the Big Dipper in their generation of the target model. The students had made a three-dimensional Big Dipper during a previous lesson. They tried to incorporate their knowledge about the movement of the Big Dipper into their model. This angle was abandoned after dialogue with their teacher about the Big Dipper's irrelevancy to the problem (Table 4.4).

Table 4.4 Macro-, meso-, and microlevel analysis of group 2

Macro		Initial models (Mi)		Enhanced models (Me)	Target models (Mt)	Model deployment (MD)
		Mi2	Mi2-1			
Meso	Generation (G)	As2		Aa2 Aa3	As2	As2 Aa5, Aa6
	Evaluation (E)	Ed3, Ed4			Ed4	Emi
	Modification (M)				Mk6	
Micro	Resource (K)	K4, K5		Kd, Kd1, Kd2, Kd3	K6, K9	K1, K5, K6, Kbd1, Kbd2, Kbd3, Kbd4
	Data (D)	D3, D4		D5	D4	

Notes: Mi2: Star A moved because of Earth's revolution; Mi2-1: Star A moved because of Earth's rotation (meaning of the term rotation is revolution); Me: Star A moved because of Earth's revolution and distance to Star A; As2: simulation by E revolution (mostly using ping pong balls); Aa2: analogy with telescope finder; Aa3: analogy with classroom students; Aa5: analogy with Big Dipper; Aa6: use Mt to explain Big Dipper; Ed3: evaluation by using data D3; Ed4: evaluation by using data D4; Emi: evaluation by method; Mk6: modification by K6; K1: stars move around Polaris; K4: Earth revolution; K5: Earth rotation; K6: visual illusion; K9: the position of stars is fixed; Kd: distance; Kd1: distance is farther; Kd2: distance is closer; Kd3: other stars are at the same distance; Kbd1: Big Dipper application; Kbd2: #2 star of Big Dipper is farthest; Kbd3: #1 star of Big Dipper is farthest; Kbd4: #2 star of Big Dipper is moving least; D3: only Star A moved; D4: other stars are not moved; D5: star A moved slow in 6 months (thinking about unsymmetrical orbit).

Table 4.5 Students' models and abstraction activities of small group 2 across episodes

<i>Ep Task</i>	<i>Macro</i>	<i>Meso</i>	<i>Micro</i>				
<i>on</i>	<i>off</i>	<i>Initial models (Mi)</i>	<i>Enhanced models (Me)</i>				
		<i>Target models (Mt)</i>	<i>Model Deployment (MD)</i>				
		<i>Generation (G)</i>	<i>Evaluation (E)</i>				
		<i>Modification (M)</i>	<i>Resource (K)</i>				
			<i>Data (D)</i>				
1	all	Mi2(L), Mi2-1(J) SI(K)	Me(JJKL)	As2(L) Ed3(K), Ed4(K, L) Aa2(IJ), Aa3(JKL)	Ed3(K), Ed4(K, L)	K4(IJK), K5(L) D3(IL), D4(K) Kd1(IKL), Kd1(I), Kd2(JJK), Kd3(K) K2-2(I), K2-1(I), Kd2(I)	D5(I)
2							
3				As4(IL)			
4			Mt(IJKL)	As2(IJK)	Ed4(JK)		K6(IJKL) D4(JK)
5				MD(IJKL)	Aa5(I), As2(K)	Mk6(JL)	
6					As2(K), As2*(K), Aa6(J) Em1(L)		Kbd1(IJL), Kbd2(IL), Kbd3(I), Kbd4(I) K6(K), Kbd1(JL)
7			-MD(I)	As2(K)			Kbd1(I), -Kbd1(all) <i>Drawing</i> (JL)
8							

Notes: Ep: episode; I, J, K, L: students in the small group 2; Mi2: Star A moved because of Earth's revolution; Mi2-1: Star A moved because of Earth's rotation (meaning of the term rotation is revolution); SJ: suspend judgement and focus on why only Star A moved; Me: Star A moved because of Earth's revolution and distance to Star A; Mt: target model; MD: model deployment; As2: simulation by E revolution (mostly using ping pong ball); As2\*: simulation by E revolution (with other students) for view from the Earth; As4: simulation according to distance to Star A; Aa2: analogy with telescope finder; Aa3: analogy with classroom students; Aa5: analogy with Big Dipper; Aa6: use Mt to explain Big Dipper; Ed3: evaluation by using data D3; Ed4: evaluation by using data D4; Emi: evaluation by method; Mk6: modification by K6; K1: stars move around Polaris; K4: Earth revolution; K5: Earth rotation; K6: visual illusion; K9: the position of stars is fixed; Kd: distance; Kd1: distance is farther; Kd2: distance is closer; Kd2-1: moving around the Sun once a year; Kd2-2: star A moved position in 6 months; Kd3: other stars are at the same distance; Kbd1: Big Dipper application; Kbd2: #2 star of Big Dipper is farthest; Kbd3: #1 star of Big Dipper is farthest; Kbd4: #2 star of Big Dipper is moving least; D3: only Star A moved; D4: other stars are not moved; D5: star A moved slow in 6 months (thinking about unsymmetrical orbit); Underline: first member who proposed the idea or expressed the position; -: rejection

Mesolevel analysis revealed that while Group 2 used simulations and employed analogies, similar to Group 1, they progressed more easily from their initial models to the target model. At the task level of SD, the analyses revealed that the students paid attention to tasks throughout the small-group activities and showed on-task behaviour as evidenced by their introduction of various knowledge and information to the class. In addition, while they began with two different initial models, they focused in on an important aspect of the task (only Star A moved) and used various kinds of knowledge and data to develop and enhance their target model. For example, at the microlevel, distance-related knowledge (Kd, Kd1, Kd2, and Kd3) was introduced, and knowledge related to the Big Dipper (Kbd1, Kbd2, Kbd3, and Kbd4) was employed. Analyses revealed that the students shared high intersubjectivity related to K4 (Earth's revolution), Kd (distance to Star A), Kd2 (Star A is closer), and Kbd1 (Big Dipper). In addition, they used three pieces of data (D3, D4, and D5). After arriving at the target model, however, they encountered difficulties due to trying to integrate information about the Big Dipper. (See Table 4.5 for a summary of the modelling processes across episodes for Group 2).

At the mesolevel, we found that two simulations (As2 and As4) and two analogies (Aa2 and Aa3) were shared by many members. For example, the use of the "telescope finder analogy" (Aa2) and "students in the front and the back of the classroom analogy" (Aa3) helped them to understand the influence of distance on the movement of Star A. At the macrolevel, in the beginning of Episode 1 (Beginning), three SDs, Mi1, Mi2, and suspended judgement (SJ), appeared. Students I and J both suggested Mi2, while Student L insisted on Mi1. Student K did not accept Mi1 or Mi2, but proposed focussing on the movement of Star A (SJ). Other students agreed with Student K at the end of this episode and reached intersubjectivity. With this intersubjectivity and by using analogies, they reached Me and Mt together (Table 4.5).

## **Discussion and conclusion**

Although the students in these two small groups developed different models via different pathways, the CCSM processes presented earlier demonstrate that modelling is an evolutionary process that changes over time and can be described at multiple levels (macro, meso, and micro) at each point in time. Specifically, the students' models evolved from initial models, to more enhanced models, and sometimes to target models. During model generation, abstraction processes included simulations and analogies (Clement, 2008; Nersessian, 2008), and a new abstraction process, hybridisation, was also identified. Initial models based on the Earth's revolution tended to be developed into enhanced models incorporating ideas of optical illusion and parallax related to the distance to Star A or related to the Earth's rotation. A new kind of student model, the ad hoc model, was identified when the students had difficulty progressing towards the target model. To evaluate the models, the students relied on data from the tasks, made predictions based on the models, and paid attention to the internal consistency of the models.

Interestingly, the students' reasons for model modification were often implicit. In developing their ideas, they frequently used simulations, sometimes with real objects, gestures, or drawings, to try to determine how the Earth's revolution related to the movement of Star A. Simulations with real-world resources, such as table tennis balls, can be regarded as a coupled system between internal and external representations (Hegarty, 2004; Nersessian, 2008). Nersessian (2008) has suggested that internal and external worlds can be conceived as forming a cognitive system that jointly carries out model-based reasoning (p. 117). In this study, students used table tennis balls to express models of the Earth revolving around the sun, and made links with the internal models they had in mind. Further research on the nature and effective ways of using a coupled system is needed.

Additionally, some students used analogies, but these analogies were not always conclusive. For example, after realising that the distance to Star A mattered, students in Group 2 were still not sure whether Star A was farther or closer to the Earth compared to other stars. The students' use of simulations, however, promoted dialogue that supported them moving their ideas forward. For example, after one student brought up an analogy of the telescope finder, other students accepted this after dialogue, resulting in intersubjectivity. Another student then introduced a second analogy, referring to the position and visual movement of students relative to the teacher in the classroom. These examples can be interpreted as two cycles of analogies enabling the abstract to be visualised through the concrete (Ilyenkov, 1982).

Hybridisation also appeared during the students' model construction. Drawing on previous learning about the Earth's rotation and diurnal motion of stars, the students incorporated these ideas when generating new models. Many students introduced the diurnal motion of stars to their Earth revolution-based models and, as a result, could not arrive at target models. In this study, data attained from the task were used for model evaluation; however, the students also made predictions based on the models they generated as a way to evaluate their models. Research has shown that students need to learn to evaluate whether their model can explain patterns in data, correctly predict the results of new observations, and determine if their model is consistent with other ideas (Cartier et al., 2001). In doing so, students better discern the applicability of new information for revising their models.

Even though the teacher encouraged student-centred exploration and discussion, CCSM also requires teachers to interact with small groups to monitor and to provide guidance and additional information. To do this effectively, class size is crucial. However, teachers in urban schools tend to have much larger classes. Currently, the average class size in Korean junior high schools is 32.8 students (OECD, 2016), which is much higher than the OECD average of 23.6. To implement CCSM effectively, teachers would benefit from smaller teacher to student ratios, as did the teacher in this study. This remains a challenge for teachers in Korean schools who want to use cooperative learning strategies.

While we collected data from six small groups in this class, we found that students in four groups copied models from their peers rather than developing their own. As a result, we could only conduct analysis on two groups. Because the goal

of CCSM activities is for students to construct and develop models through collaborative investigation and discussion with peers and the teacher, this result was disappointing. However, this practice may have occurred because Korean students feel pressured to get the “right answers” so they can get high scores to enrol in top schools. Korean traditional culture may also have contributed to this practice. While exploring cultural characteristics of students engaged in CCSM activities in Korea, Lee (2013) found that students were highly dependent on other students and teachers, and many hesitated to state their own opinions in order to avoid conflicts. We believe the CCSM approach can contribute to the goals of the national curriculum, which seeks to foster scientific inquiry, thinking skills and problem-solving abilities, but additional research is needed to understand how to better support effective implementation of CCSM in Korea.

The framework developed and used in this study to understand modelling can help teachers by providing a sophisticated lens and blueprint for evaluating lessons, and can help teachers understand the models students construct, and anticipate how their models may evolve. With this framework, teachers can adapt to and manoeuvre through even unanticipated situations in science classes, and differentiate and identify abstract processes and the resources used by students. An important implication of CCSM is that students' learning is an evolutionary process, starting with the students' own resources and initial models aimed at target models. Even though students' initial models may be naïve or far from the target models, they are valuable because learning should be built upon them. With initial models, teachers can better understand what resources students bring into the classroom, and how they think. Students' ideas and resources have to be exposed, used, and challenged during lessons. To do so, teachers should organise teaching sequences and the learning environment to guide students, and they should provide key constraints for model building. Otherwise, students' may stick to their own ideas and not develop target models, even though teachers try to lead them by emphasising scientific ideas.

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# 5 Hong Kong students' characteristics of science learning in relation to ROSE

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## Introduction

According to a consolidation report released in 2015 by the Organisation for Economic Co-operation and Development (OECD), Hong Kong students' basic skills (e.g., mathematics and science skills) which are needed for economic participation ranked second (just behind Singapore, with a small difference in their mean scores) out of 76 regions/countries in the world (OECD, Hanushek, & Woessmann, 2015). The findings were based on the PISA 2012 and TIMSS 2011 reports of students' performance tests (IEA, 2011; OECD, 2014). In the PISA 2012 study on students' performance in science, Shanghai was rated top of the list with a mean score of 580, while Hong Kong and Singapore ranked second and third with scores of 555 and 551, respectively. The difference between Hong Kong and Singapore is not statistically significant. However, the report also noted that "Hong Kong-China, Ireland, Japan, Korea and Poland performed at or above the OECD average in science in 2006 and by 2012 showed an improvement in science performance of more than two score points per year" (p. 216). This means that there was improvement shown among Hong Kong students but not in Singapore.

Because of the political influence of international rankings such as from PISA and TIMSS, a number of researchers have investigated the academic successes of Hong Kong or Chinese students' science learning in relation to different characteristics, factors, and assumptions. For example, Ho (2010) revealed from a multi-level analysis of the Hong Kong PISA 2006 data (with 4,645 students from 146 schools) that parental support significantly correlated with students' science performance, while science-related activities outside of school were highly effective for enhancing students' science self-efficacy and achievement. Applying a similar analysis to the same data set, Sun, Bradley, and Akers (2012) concluded that gender (favouring boys), families with higher socioeconomic status, motivation and self-efficacy were positive predictors of students' science achievement. Furthermore, they reported that the school enrolment size (the total number of students in a school) was positively correlated with science achievement. However, Lam and Lau (2014) used hierarchical linear modelling to examine the factors underlying Hong Kong students' science achievement in PISA 2006 and

suggested that school student intake (i.e., quality of students admitted into the Secondary 1 class) was the major mediator accounting for the effect of school size. Their study also showed that most of the parental factors have rather limited or insignificant impacts on students' science achievement after taking into account student attitudes. In other words, factors such as gender and family socioeconomic status do not meaningfully contribute to the overall better science achievement of Hong Kong students as a group compared with those in other OECD countries/regions. Therefore, this chapter adopts a different approach to characterise Hong Kong students' science learning by asking the following two research questions:

- 1 What are the key socio-political, educational, cultural, family, or personal factors that may affect the teaching and learning of science in Hong Kong as a whole? How do they influence students' science learning?
- 2 Apart from interest and performance in science, what are Hong Kong students' science-related experiences within and outside the school environment, and what are their views regarding future career choice?

This chapter addresses the first research question by conducting a literature review of the key aspects of Hong Kong which may affect the development of science education, including the effects of socio-political changes on education policies over the last three decades, curriculum reform in science education since the return of Hong Kong to China in 1997, the effects of medium of instruction on students' science learning, and the characteristics of Chinese/Hong Kong learners as influenced by the CHC (Biggs, 1996; Law, 2002; Ryan & Slethaug, 2010; Watkins & Biggs, 2001). The second research question is addressed by consolidating the findings of the ROSE study, which reveals Hong Kong ninth-grade students' non-cognitive aspects of science learning.

## **A brief overview of the education context in Hong Kong**

### *Socio-political changes and effects on education policies*

Political transitions and shifts in socioeconomic development often have significant impacts on shaping education policies and practices, as evident in many East Asian countries and regions during the era of postcolonial transitions and globalisation (Bray & Lee, 2001). From 1842 to 1997, Hong Kong was under British colonial administration with an education system that was substantially different from that of Mainland China. However, after the Sino-British Joint Declaration was signed in 1984, Hong Kong underwent a transition period in preparation for her return to China in 1997 under the "one country, two systems" principle, with a high degree of autonomy as outlined in the Basic Law (Hong Kong Yearbook, 1997). A high-profile education committee was established by the Hong Kong government to draft five Education Commission Reports during the period 1984–1992 to introduce a number of new education

policies, such as the phasing out of the Junior Secondary Entrance Examination; the expansion of technical, vocational and higher education (with rebranding and the creation of several new universities and an institute for tertiary teacher education); and the establishment of the Hong Kong Council for Academic Accreditation (for the accreditation of local degree programmes) and the Curriculum Development Institute (for drafting a Hong Kong version of school subject curricula instead of cloning them directly from the United Kingdom) (Morris & Adamson, 2010).

Major new education policies or reforms have been implemented since 1997, including language policy to use the students' mother tongue for teaching; advocacy of information technology in education; establishing the Quality Education Fund to improve school education; a substantial increase in sub-degree programmes and student numbers, with 60% of 17–20 year olds participating in postsecondary education; drastically changing the senior secondary and tertiary education systems (from the British system of two-year certificate education + two-year advanced level education + three-year degree education to the Chinese system of three-year senior secondary education + four-year degree education); and consequent reform of the senior secondary curricula (Morris & Adamson, 2010; Morris, Kan, & Morris, 2001).

Regarding socioeconomic development over the last three decades, Hong Kong has undergone a substantial shift towards a knowledge-based economy with a high dependence on international trade and finance, with over 93% of her gross domestic product (GDP) generated from the services sector in which about half of her labour force is engaged in wholesale and retail trade, finance, restaurants, and hotels. The manufacturing sector only accounts for 7% of her GDP as most of the factories were relocated to Mainland China in the early 1990s (Census and Statistics Department, 2014). Hence, jobs in science and technology are very limited in Hong Kong despite the creation of the Science Park and the Cyberport in the last decade.

### *Curriculum reform in science education*

Hong Kong has a population of around seven million, comprising approximately 95% Chinese and 0.5% white by ethnicity, plus about 4% consisting of domestic helpers from Southeast Asia (Census and Statistics Department, 2014). In essence, its education system was adopted from the British before 1997 and later evolved to align with international systems (similar to those in the United States and Mainland China) through a series of educational reform initiatives as briefly mentioned earlier. Currently, there are around 650 primary and 450 secondary schools, most of which are financially subsidised by the government.

Science education is one of the eight Key Learning Areas of the school curriculum as embraced in the Hong Kong education reforms of the early 2000s. The framework for science education is designed to provide “Learning experiences for students to develop the necessary scientific knowledge and understanding, process skills, values and attitudes, for their personal development and for contributing

towards a scientific and technological world” (Curriculum Development Council, 2001, p. iii). Its content consists of six strands, namely Scientific Investigation, Life and Living, the Material World, Energy and Change, the Earth and Beyond, and Science, Technology, and Society. It is implemented in the six years of primary school through the general studies subject that was developed in the early 1990s by merging science, social studies, and health education into a single integrated curriculum (Curriculum Development Council, 2011).

In the three years of junior secondary education, science is a core subject taught in most schools and has been implemented for over four decades with the latest version of the curriculum revised in 1998 (Curriculum Development Council, 1998). Its conceptual framework is composed of the three interrelated areas of matter, energy, and life, all of which are immersed in scientific investigation and linked with students’ daily life through the STS approach.

Science education at the senior secondary level has undergone drastic changes due to the aforementioned restructuring of the education system, implemented in 2009. In essence, the three traditional subjects of physics, chemistry, and biology, which were offered in the two-year certificate of education and the two-year advanced level (Advanced Supplementary Level), were replaced by three corresponding science subjects offered in the new three-year diploma of secondary education (DSE) together with a new combined science course (a combination of two traditional science subjects with less content) and a new integrated science course (Yeung, Lee, & Lam, 2012). All the five new science curricula emphasise the nature of science and science-technology-society-environment connections, and include school-based assessment that accounts for around 20% of a student’s public examination score. The education reform also strongly advocates the use of information technology in education and life-wide learning to enhance and extend students’ science learning within and outside school settings. For example, a new physics programme was recently developed in the Hong Kong Ocean Park to facilitate senior secondary students’ learning of mechanics topics in the DSE physics through the innovative use of digital technology and rides in the theme park (Tho, Chan, & Yeung, 2015).

### *Influences from the medium of instruction*

During the era of British colonial governance, English as a medium of instruction (MOI) was preferred by most secondary schools and parents (for better career prospects and further study opportunities) irrespective of students’ capabilities of learning through English. The English language was also believed to be beneficial to Hong Kong students’ science learning because the Chinese language lacks the vocabulary for precise definition of many scientific terms and concepts, or its words may have very different meanings in everyday use, resulting in difficulties for students when developing their understanding of scientific knowledge (Cheng, 2011; Fung & Yip, 2014; Yip, Tsang, & Cheung, 2003). However, we, as science teacher educators, paid over a hundred visits to different secondary schools for supervision of student teachers’ teaching

practice during 1995–1998 and noticed that many science teachers actually used Cantonese with English terms in their junior secondary science classrooms, and required students to complete assignments and assessment tasks in simple English. Lin (2006) pointed out that such bilingual pedagogies in science classrooms are helpful to students' learning of science when they have limited proficiency in English.

In 1998, the government introduced a new language policy, and as a result only about 25% of secondary schools now use English as their MOI (English-medium instruction, or EMI), based on the quality of the school's prospective S1 (Grade 7) students and its teachers' English proficiency. All other schools use the students' mother tongue, (i.e., Chinese as MOI (CMI)) for teaching science and other non-language subjects at the junior secondary level. Subsequently, from the results of a science achievement test administered to S2 (Grade 8) students in 75 CMI and 25 EMI schools, Yip et al. (2003) found that EMI students performed much more poorly than the CMI students because EMI students' science learning was made more difficult by their insufficient command of English. In a three-year study of 199 S4 (Grade 10) physics students, Fung and Yip (2014) found that CMI has a stronger impact on empowering low achievers to attain a higher level of performance in conceptual assessments and physics examinations, but EMI was more appropriate for the high achievers.

### *CHC and characteristics of Hong Kong learners*

Many students from CHC regions or countries (i.e., places with traditions and beliefs strongly influenced by the Confucian-heritage cultures), such as Mainland China, Hong Kong, Taiwan, Singapore, Korea, and Japan are well known to be very hardworking, and to achieve well in science and mathematics in international comparative studies, as well as in STEM (science, technology, engineering, and mathematics) subjects at colleges or universities when students study abroad (Law, 2002; Watkins & Biggs, 2001). Early research literature described this phenomenon as the 'success' of CHC education and the related rote learning, examination-oriented learning, memorisation, and passivity seen as characteristic of Chinese learners' style of learning (Biggs, 1991; Kennedy, 2002). However, from a comparative study of ethnic Chinese students in Hong Kong and original Australian students of equivalent grades, Biggs (1991) rejected the aforementioned stereotype and found that Hong Kong students "portrayed a profile of motives and learning strategies that suggested a more 'academic' approach to learning and studying than that of Australian secondary and tertiary students" (p. 27). Chan and Watkins (1994) further revealed from a questionnaire survey of Hong Kong secondary students that their preferred learning environment was strongly related to a deep approach to learning. However, students perceived their existing classroom environment "to be relatively competitive and teacher controlled and as encouraging rote-learning" (p. 233).

By studying parents' beliefs about education in CHC communities, Lam, Ho, and Wong (2002) were able to identify some key factors to account for the success

of CHC education. They found that Hong Kong parents often hold schools and education in high regard, are highly engaged in their children's education, are willing to make the necessary sacrifices (e.g., career opportunities, money, and social activities), attribute the success of education to their children's persistence and effort, and accept a definite division of role and duty between schools and parents. Furthermore, Ryan and Slethaug (2010) ascribed the strong support from family to the CHC tradition, which values education as the most important means for social advancement, regards students' achievements as their own, and requires children to respect teachers and historical texts.

Having considered the Hong Kong education context, the possible influences of the socio-political changes, curriculum reform, MOI policy and the CHC context, the following section explores the findings of an international comparative study and, in particular, findings related to the non-cognitive or affective domain of Hong Kong science students.

## Research methodology

### *The ROSE Research Instrument*

Based on the previous 'Science-And-Scientists' study by Sjøberg (2000), a large-scale international comparative project called ROSE was initiated in 2002 by Schreiner and Sjøberg (2004) to collect data on students' non-cognitive or affective domain of science learning (including interest, attitudes, values and career or study plans related to S&T) from over 40,000 15-year-old students in approximately 40 countries or regions. It overcame a major problem of earlier attitudinal research studies where there had been no easy way to undertake a comparative study between student responses collected by different questionnaires or research instruments (e.g., Blalock et al., 2008; George, 2006).

### *Data collection and analysis*

A Chinese version of the ROSE research instrument was developed by Yeung and Cheng (2008) and first administered to 70 classes in Hong Kong, Shanghai, and Guangzhou, China as a pilot study in 2007. Around 2,400 valid questionnaires were returned and their overall reliability was very high (Cronbach's alpha = 0.98). Yeung and Cheng (2010) reported on an ordinary (first-level) exploratory factor analysis (EFA) to render 25 key factors from 160 items after successive data reduction processes. Those factors satisfied the screen test and Kaiser's criteria with an eigenvalue > 1. Furthermore, they calculated the factor scores  $FS_i$  by using factor loadings  $f_{ij}$  as weights in accordance with the following formula (Yeung & Li, 2015):

$$FS_i = \sum_j f_{ij} S_j / \sum_j f_{ij}^2 \quad (1)$$

where  $S_j$  is the average score of the students for the  $j$ th questionnaire item.

Based on a critical review of the nature of the 25 factors and a second-level EFA, they obtained four distinct categories of factors (i.e., factors of factors) for the ROSE instrument, namely 13 factors in A (interest in learning science topics) representing what students want to learn; six factors in B (science-related experiences) representing students' S&T related experiences in their daily life and out-of-school activities; three factors in C (job/career orientations) representing students' considerations of their career orientations or choices of jobs; and another three factors in D (views on S&T issues) representing students' views on S&T and related issues.

A full-scale ROSE study was subsequently conducted in Hong Kong (during the 2009/10 school year), with 1,992 questionnaires returned from 57 classes of S3 students in 28 different schools (Yeung & Cheng, 2010, 2011). The male to female ratio was 51.3%: 48.7%. Confirmatory factor analysis applied by Yeung and Cheng (2011) confirmed the initial model of the simplified structure of the ROSE data set, justifying the use of the EFA factor loadings and structure from the pilot data in the present Hong Kong full-scale data. To address our second research question, we report in Tables 1 and 2 descriptions of those nine factors in categories B and C and their constituent ROSE items and factor loadings. Using Eq. (1), the mean factor scores for the Hong Kong data set were calculated in Tables 5.1 and 5.2 together with those from Shanghai and the international ROSE study (Schreiner, 2006; Sjøberg & Schreiner, 2005).

## Results and discussion

### *Science-related experiences*

Table 5.1 shows that Hong Kong students of either gender had mean factor scores < 2.0 (based on the 4-point Likert scale, with 1 = never and 4 = often) in factors FB1–3, indicating that they had very limited experience of outdoor living (e.g., milking animals, caring for animals on a farm, participating in hunting or producing dairy products, etc.), hands-on activities for transportation (e.g., using a crowbar, a wheelbarrow, a rope and pulley for lifting, mending a bicycle tube, etc.) and using Do-It-Yourself (DIY) tools and models (e.g., using an air gun or rifle, making a bow and arrow, slingshot, catapult or a model such as a toy plane or boat, etc.). These findings are similar to those of Shanghai and Xinjiang students (Yeung & Li, 2015), but are much lower than those of Finnish students (based on an EFA of their ROSE dataset by Lavonen, Byman, Uitto, Juuti, & Meisalo, 2008) and Greek students, for whom Christidou (2006) obtained factor scores of the values 2.45 to 3.38 for the five factors of students' out-of-school experiences. Students in Hong Kong and all other places surveyed in the ROSE study possessed the richest experiences in using tools such as thermometers, length-measuring tools, cameras, and computers compared with other kinds of science-related experiences.

For students in both Hong Kong and Shanghai, statistically significant gender differences were found for factors FB1 'outdoor living experience', FB2



Table 5.1 Factors and mean factor scores (with SD in brackets) for six factors on students' science-related experience and their gender differences as obtained from the full-scale ROSE study in Hong Kong

Factor Label	Description of factor (constituent ROSE items and corresponding factor loadings)	ROSE Study in Hong Kong			ROSE Study in Shanghai
		Boys only	Girls only	Both	
FB1	Outdoor living experience (H10*0.76, H07*0.72, H15*0.70, H11*0.69, H21*0.68, H19*0.64, H18*0.61, H22*0.59, H06*0.55, H16*0.55, H14*0.53, H20*0.50)	1.87(0.70)	1.77(0.59)	1.82(0.65)**	1.67(.63)***
FB2	Hands-on experience of doing transportation (H57*0.83, H58*0.75, H59*0.72, H56*0.70, H61*0.59, H55*0.50)	1.97(0.79)	1.69(0.65)	1.83(0.74)***	1.74(.71)***
FB3	Daily life experience of DIY tools and models (H33*0.71, H32*0.67, H35*0.65, H34*0.56, H36*0.54)	2.20(0.75)	1.75(0.64)	1.98(0.73)***	1.94(.72)***
FB4	Students' medical experience (H26*0.55, H28*0.53, H27*0.50, H29*0.41)	2.17(0.74)	2.10(0.65)	2.14(0.70)*	2.30(.66)
FB5	Out-of-school experience in learning science (H12*0.69, H13*0.65, H09*0.62, H08*0.60)	2.56(0.69)	2.54(0.65)	2.55(0.67)	2.74(.68)
FB6	Experience of using handy tools and computers (H42*0.70, H43*0.67, H41*0.66, H31*0.54, H38*0.51, H48*0.48, H51*0.44, H40*0.43)	2.88(0.63)	2.98(0.61)	2.93(0.62)***	2.82(.67)

\*\*\* For p < 0.001; \*\* for p < 0.01 and \* for p < 0.05 for cases with statistically significant gender difference.

'hands-on experience of transportation', and FB3 'daily life experience of DIY tools and models', with boys generally having richer experiences than girls. The gender-specific differences seem to be closer to those of the developed rather than developing countries or regions as revealed by Sjøberg (2000). These findings are also similar to Johnson's (1987) analysis of the 1984 APU survey of 11-year-old boys and girls in which boys were more often engaged in activities such as making models from a kit, playing pool, billiards or snooker, playing with electric toy sets, creating models using Lego, and taking things apart to see inside. Girls had more experience of activities such as knitting or sewing, weighing ingredients for cooking, and collecting/looking at wild flowers. However, Hong Kong girls had more experiences than boys in the medical field (FB4) and in using handy tools and computers (FB6). This is consistent with the Finnish findings obtained by Lavonen et al. (2008) in which girls had more experience than boys in FE2, Measuring and observing with simple tools and FE3, Observing natural phenomena and collecting objects. On the other hand, Christidou's (2006) factor analysis of the ROSE data of Greek students revealed that girls had more experience than boys in Factor 2, Using instruments and technological devices; Factor 3, Seeking information about nature; and Factor 5, Cuisine and handicrafts. The study by Jones, Howe, and Rua (2000) found that in the USA, more girls than boys had prior experiences of bread-making, observing birds and stars, knitting, sewing, and planting seeds.

### *Job/career orientations*

As shown in Table 5.2, Hong Kong students of both genders gave highest priority to jobs with a high degree of autonomy and independence (FC1, e.g., making my own decisions, working with something I find important and meaningful, or which fits my attitudes and values, becoming 'the boss' at my job, etc.), rated highly the need to get along with others (FC2, e.g., helping other people, working as a part of a team, and working with people rather than things), and showed least preference for jobs requiring creativity in S&T (FC3). The relatively lower preference for FC3 may be ascribed to students' lower preference for S&T jobs, or it may be correlated with their lack of development in creativity due to the overwhelming teacher-centred pedagogies and excessive drilling exercises in an examination-oriented learning environment as commonly practised in most Chinese classes. However, it is interesting to observe that the Shanghai and international ROSE data revealed similar findings.

For factors with statistically significant gender differences, both Hong Kong and Shanghai girls rated FC1 with more importance than boys, but only Hong Kong girls did so for FC2. In comparison with Western learners, boys in Sjøberg's (2000) SAS study considered 'control other people', 'become famous', 'make and invent new things' and 'earn lots of money' to be more important for their choice of job, while girls put more importance on 'work with people instead of things' and 'help other people'. Similar findings in gender differences were also reported by Jones et al. (2000). Furthermore, girls in Warrington and Younger's

Table 5.2 Factors and mean factor scores (with SD in brackets) for Hong Kong students' job/career orientations as based on the ROSE study in Hong Kong and comparison with those results obtained in the Shanghai and international ROSE study

Category	Factor Label	Description of factor (constituent ROSE items and corresponding factor loadings)	ROSE study in Hong Kong			Other ROSE study	
			Boys only	Girls only	Both	Shanghai	International
Job/career orientations	FC1	Jobs of high degree of autonomy and independence (B13*0.65, B15*0.61, B16*0.58, B24*0.57, B25*0.54, B14*0.54, B09*0.52)	3.14(0.58)	3.25(0.50)	3.20(0.55)***	3.36(0.53)***	3.14
	FC2	Jobs need to get along with others (B02*0.68, B26*0.61, B01*0.52)	3.01(0.70)	3.10(0.63)	3.05(0.67)**	3.17(0.70)	2.77
	FC3	Jobs requiring creativity in S&T (B10*0.72, B11*0.62, B06*0.62, B07*0.50, B04*0.48, B08*0.45, B03*0.43)	2.56(0.65)	2.52(0.63)	2.54(0.64)	2.80(0.61)	2.35

\*\*\* For p < 0.001; \*\* for p < 0.01 and \* for p < 0.05 for cases with statistically significant gender difference.

(2000) survey in the United Kingdom tended to choose a job dominated by female employees even though they might have more restricted income levels and opportunities. That survey also found that boys tended to follow traditionally gendered paths in their career orientation, with around half of them selecting stereotypically male-dominated jobs in the fields of science, engineering, and technology.

## **Conclusions and educational implications**

The first part of the chapter outlines four key aspects (socio-political changes, curriculum reform, MOI policy and the CHC context) of Hong Kong that may have important influences on the future development of science education. The socio-political changes over the last three decades have led to a number of new education policies and a drastic change in the education system. Essential elements of the curriculum reform in science education and MOI are reported earlier, and describe the science content learned by Hong Kong students. The MOI policy seems to improve low achievers' performance in science learning without sacrificing the needs of high achievers. A description of cultural effects of CHC on Hong Kong learners was provided to address common misconceptions. In particular, strong support from parents or family for children's education was clearly identified as a very important and favourable factor in the CHC tradition, which helps to drive better performance in science education for Hong Kong learners.

In the second part of the chapter, evidence from the ROSE questionnaire was used to reveal students' characteristics in relation to their science learning. For example, Hong Kong students had very few science-related experiences compared with those of other countries, except in relation to the use of handy tools and computers. They preferred jobs with a high degree of autonomy and independence rather than jobs requiring creativity in S&T.

Finally, although there are challenges in the Hong Kong education system, the MOI policy and the CHC may provide some explanations for students' positive science performance. A comparison of the ROSE data from Hong Kong and other countries revealed differences in students' jobs/career orientations.

It is hoped that these discussions will contribute to a more comprehensive and evidence-based debate of Hong Kong students' characteristics of science learning among the international science education community. The work is also useful for generating directions for further research; specifically, the need to explore further factors underpinning good student performance in science. Moreover, education policymakers and science educators may consider formulating policies and interventions aligned with factors that enhance students' science performance.

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**Part II**

**Science pedagogy**





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# 6 Investigating the impact of inquiry-based instruction on students' science learning in Taiwan

*Hsiao-Lin Tuan and Chi-Chin Chin*

## **The influence of inquiry-based curriculum reform in Taiwan**

Taiwanese culture has an emphasis on education. People generally believe that education can change an individual's future, and students, parents, and teachers all put a great deal of effort into helping students pass competitive examinations in order to gain admission to prestigious universities. Under the current education system, students are required to master test-taking skills in order to be admitted by higher-ranking schools and/or universities. Given this context, high school science teachers spend less time teaching hands-on laboratory skills, and rote learning tends to be a common learning strategy at the secondary school level. This phenomenon is persistent in formal education due to the pressure of peer competition and parents' expectations (Chin, 2007, 2014). In the 1990s, the National Science Education Standards (National Research Council, NRC, 1996), developed in the United States, was introduced to Taiwan. The spirit of inquiry-based instruction, embedded in this curriculum, has resulted in substantial reflection on the Taiwanese science education system. A number of research projects have been funded by the National Science Council (NSC), allowing science educators and scientists to carry out empirical studies and evaluate educational interventions. This chapter focuses on the literature related to inquiry-based instruction produced in Taiwan over the past 20 years.

From 1991 to 2014, the Ministry of Science and Technology of Taiwan (MOST, formerly the NSC) granted funding for 204 research projects related to inquiry-based instruction, learning, and teaching. Among them, the majority of the projects (N = 197, 97%) were carried out after 2000. Meanwhile, in 2000, the Ministry of Education in Taiwan implemented the nine-year integrated curriculum from Grade 1 to Grade 9. The goals of the new science curriculum addressed the inquiry-based learning approach to learn science (Ministry of Education, MOE, 1999). Therefore, such a *nine-year continuous curriculum* might play a key role in promoting inquiry-based instruction research.

In 2007, the National Science Council proposed a landmark document, the *White Paper on Science Education* (NSC, 2007), to emphasise the importance of inquiry-based instruction in the science education of Taiwan:

Science inquiry that focuses on investigating activities should be adopted in science education to enhance students' learning of basic scientific knowledge and skills, nurture the habit of scientific thinking, and use scientific methods to do exploration and argumentation for solving the problem. Based on such practices learned in the inquiry process, students are expected to build an epistemological understanding of science, a positive attitude toward science, and abilities of innovation and caring for the environment. In short, science education with an emphasis on inquiry aims at enhancing both individual and national well-being.

(p. 8)

In this document, science inquiry in science education in Taiwan was also defined:

Science education in Taiwan should train our students with the abilities needed to do science inquiry. These include the skills of conducting experiments, proposing hypotheses, designing the experimental process, collecting the data, presenting the findings, making inferences, reflecting on and critiquing the findings, and searching for and accumulating scientific knowledge. All of these are identified as science process skills.

(p. 10)

Accompanying the shift to a science inquiry focus, MOST has supported the professional development of in-service teachers since the 2000s.

In addition to reform pressures from within the country, competition within the international community is also critical. Taiwan first participated in the *Programme for International Student Assessment* (PISA) in 2006. Both government and citizens' focus on the performance of Taiwanese students, and Taiwan's ranking in PISA is taken as a measure of the effectiveness of school education. Since scientific inquiry is emphasised by both PISA and science curricula internationally, both the MOE and MOST strongly emphasise inquiry-based instruction in classroom teaching. The goal of the science curriculum has shifted from acquiring scientific knowledge, to teaching students to use inquiry-based and practice-based learning approaches to acquire scientific knowledge, and to cultivating students' scientific and technological literacy (MOE, 1999). Based on this goal, the MOE of Taiwan introduced an inquiry-based curriculum in 2000 that emphasised students' competence in science inquiry and thinking skills. However, from the international perspective of an inquiry education paper (Abd-El-Khalick et al., 2004), Tuan discussed the obstacles to implementing inquiry curriculum in Taiwan as being "examination-related anxieties, accountability pressures, lack of instructional time, and

efficiency beliefs [which] directly influence the way teachers approach science teaching in Taiwanese classrooms” (p. 411). In other words, the implementation of inquiry-based instruction in science classrooms is a challenging task for science educators as well as practitioners in Taiwanese society.

## **Inquiry-based instruction learning outcomes**

In the following sections, we present research published in master’s theses and Chinese journals of science education over the past 20 years to illustrate how Taiwanese science teachers, as well as science educators have addressed inquiry-based instruction in school science class settings and teacher education programmes. The rationale to select these theses or local journal articles is to present how science teachers/educators carried out inquiry-based instruction research in their own classes, and the various outcomes arising from these studies. Master’s theses are specifically included since action research and case studies are very popular research methods employed by our in-service teachers. These studies represent good examples for an international audience to gain insights into how teachers implement inquiry-based instruction in the classroom, the problems they face, and the solutions they identify. Studies from the well-known *Chinese Journal of Science Education* were also selected. These studies are all written in Chinese; therefore, it is a good opportunity to present them here and to share with an international audience the perspectives of both Taiwanese researchers and practitioners.

### ***Inquiry-based instruction and students’ motivation regarding science learning***

Chen (2012) investigated the change in one class of eighth graders’ science learning motivation and inquiry competency after incorporating inquiry-based instruction in a science class for one year. Her study consisted of two classes of eighth graders with similar learning ability in science. One (N = 32) was assigned as the experimental group and the other (N = 33) as the control group. Chen then applied the 5E (engagement, exploration, explanation, elaboration, and evaluation) (Bybee, 1997) inquiry-based instruction with the experimental group, while maintaining a traditional instructional approach with the control group. Nine students (three for each of high, middle, and low achievers) were interviewed at the beginning of the first semester, and at the end of the first and second semesters. She also collected other data such as students’ worksheets, video-recordings of her teaching, her own reflection journal, and records of the bi-weekly discussions with her university-based research team. Moreover, students in both groups completed the questionnaire, Students Motivation toward Science Learning (SMTSL) (Tuan, Chin, & Shieh, 2005) before, during, and after the study period. SMTSL includes self-efficacy, science learning value, active learning strategies, achievement goals, performance goals, and learning environment stimulation. The scientific inquiry scoring rubric (Oregon Department of

Education, 2005) was implemented with the experimental group to assess the change in students' inquiry competency. The findings indicated that inquiry-based instruction using the 5E approach can significantly ( $p < 0.05$ ) enhance students' learning motivation in the aspects of science learning value (students' motivation was induced by perceiving the value of learning science) and learning environment stimulation (students' motivation was induced by the teacher's teaching, curriculum material, and peer interaction). In the experimental group, students' inquiry competencies showed significant ( $p < 0.01$ ) improvement in the interim as well as the post-test in the aspects of designing an experiment, interpreting the data, and analysing results.

Zhan (2012) taught one-eighth grade class using 5E inquiry-based instruction for one semester and then shifted back to traditional instruction in the second semester. Her findings indicated that after one semester of inquiry-based teaching, students' learning motivation as well as their inquiry-based competencies showed significant gains. However, by the end of the second semester, all the scales in SMTSL and inquiry competencies decreased due to shifting back to traditional teaching. However, the post-test results were still higher than those of the pre-test. In other words, even when teachers revert to traditional teaching, students' learning motivation, as well as inquiry competencies, can be maintained, at least over the period of one semester.

Tsai, Tuan, and Chin (2007) also used Students' Motivation toward Science Learning (Tuan, Chin, & Shieh, 2005) as the instrument for investigating their changes through a semester-long, nested-inquiry instruction for eighth-grade students. The results showed that the experimental group ( $N = 155$ ) demonstrated a significant increase in their attitudes compared with the control group ( $N = 140$ ). They also scored significantly higher than the control group on the subscales of 'Self-Efficacy', 'Active Learning Strategy', 'Science Learning Value', and 'Learning Environmental Stimulation'.

### *Inquiry-based instruction and students' motivation and creativity*

Cheng (2012) investigated the effect of one semester of inquiry-based instruction on students' learning motivation and scientific creativity with one eleventh-grade class. She conducted four units of inquiry-based instruction (non-linear fluid, colorful solution, triathlon, chemical reaction) in her study. For instance, related to the topic of colorful solution, Cheng prepared an acid and base solution, indicator, and tubes in front of the class. She raised questions testing the students' understanding of acid-base neutralisation. The students' task was to use the acid, base solutions and different indicators provided in the lab to prepare solutions with pH values equaling 1–4 and 10–14, and to write down the color of these solutions with different pH values. They needed to design and implement the tests and finally write down all the possibilities of their solutions. Cheng then graded the students' worksheets for the four inquiry units on their novelty, solution, elaboration, and integration. The study used SMTSL to investigate the students' learning motivation before, during, and after the guided-inquiry-based

intervention. The findings showed that their learning motivations significantly improved in the areas of self-efficacy, active learning strategy, and science learning value. Cheng also adopted the Creative Product Semantic Scale (Lin, 2002). The findings showed that the inquiry-based instruction also enhanced the students' creativity. Furthermore, students with high, medium, and low motivation all showed an improvement in their creativity after one semester of inquiry-based instruction.

Wang (2008) investigated one class of 28 gifted students, measuring the changes in their creativity after implementing three semesters of nested-inquiry-based instruction (NIB) (Tsai, Tuan, & Chin, 2007), which consists of two learning cycles, one comprised of textbook-based laboratory activities, and the other mainly consisting of explorations based on students' everyday experiences. For instance, in the acid-base neutralisation unit, the teacher taught all of the essential concepts (electrolytes, acid, base, titration, indicators, etc.) to the students, and guided them to conduct textbook lab activities and demonstrate the necessary lab as well as inquiry skills (such as how to prepare acid-base solutions, how to conduct titrations, and how to test for electrolytes). After the students learned all of the necessary inquiry skills and knowledge, the teacher then provided daily life examples and asked the students to find ten solutions in their living environment and prove whether the solution is acid, base, or neutral providing two to three pieces of evidence. In this daily life setting, the students could elaborate their inquiry skills learned in the lab setting. The NIB addresses Taiwanese science teachers' concerns about teaching scientific knowledge and provides opportunities for students to develop their inquiry competencies. Each semester, teacher Wang taught two NIB units and videotaped students' involvement, interviewed students to clarify their ideas about scientific inquiry, collected students' worksheets, and reflected on these units. In total, six units were implemented over the course of the study. The worksheets in each NIB unit focused on how students designed and conducted their experiments, collected data, and generated conclusions during their inquiry activity. At the end of each semester, the students completed a two-hour test intended to measure students' science creativity. Again, an example of one of the tasks would be helpful. The three tests were evaluated using Torrance's (1974) scale: comprising fluency, flexibility and originality. The findings did not show a significant increase in students' creativity scores after the second semester, but the scores did increase significantly between the second and third semesters. This suggests that prolonged exposure to NIB may be necessary to significantly impact students' creativity.

### *Inquiry-based instruction and students' inquiry competencies*

Hung (2010) adopted the thinking-based inquiry-learning approach to teach five classes of eighth graders ( $N = 172$ ) as the experimental group through exploration, explanation, communication, and reflection, while another five classes of eighth graders ( $N = 172$ ) were taught by the textbook-based approach as the control group. The findings revealed that the experimental group performed better than the control group in inquiry competence such as formulating alternative

hypotheses, evaluating, selecting hypotheses, designing experiments, predicting results, and giving explanations.

Yang, Chen, and Changlai (2011) also used a quasi-experimental design to investigate the effect of problem-based learning (PBL) on the problem solving and critical thinking of fourth-grade students. The experimental group and control group implemented PBL and lecture-based teaching, respectively. The findings revealed that PBL promoted the problem-solving and critical-thinking abilities of fourth graders.

Lee, Lin, and Hung (2010) used a quasi-experimental design in two elementary classes to investigate the effects of inquiry teaching compared to a traditional science teaching approach on science argumentation for 15 months. The results indicated that the experimental group exhibited more significant growth in their science argumentation than the control group. A quasi-experimental study was also adopted by Lu, Hong, and Tsai (2008) to investigate the effects of “5 Why scaffolding strategies” on fourth-grade students’ science achievement and inquiry ability. The results revealed that the experimental group outperformed the control group in science concepts and techniques of scientific inquiry ability.

Yang and Wang (2007) used a class of fifth-grade students ( $N = 31$ ) to investigate their growth of inquiry competence through the whole-semester, guided-inquiry instruction. The field-notes, videotaping, interviews, pre- and post-achievement tests, and Student Inquiry Ability Self-Assessment Scale were used for data collection. After a semester-long instruction, students’ science achievement and inquiry abilities were significantly improved.

Tsou (2007) summarised 34 studies conducted in Taiwan from 1991 to 2006 that focused on inquiry-based instruction outcomes and found that inquiry-based instruction was associated with improvement in students’ academic achievement, science attitudes, conceptions of the nature of science, science process skills, and inquiry competency. She also identified that in order to observe a desirable outcome of inquiry-based instruction, the time spent on the instruction needs to exceed one month.

### *Inquiry-based instruction and students of diverse abilities*

Chen, Tuan, Tsai, and Chang (2008) incorporated NIB (Tsai et al., 2007) in two eighth-grade classes for investigating high- and low-achieving eighth graders’ motivation and inquiry ability after experiencing a shift in teaching contexts throughout two continuous semesters. These two classes were taught with inquiry-based activities, and the achievement levels of the students ( $n = 65$ ) were initially mixed. By the end of the first semester, which was also the middle of the research period, the school introduced a streaming policy that re-assigned students into classes according to their academic achievement. As a result, 27 of the 65 students, identified as high achievers, were transferred from the inquiry-based classes to traditional teaching classes (the ‘transferred out’ group;  $n = 27$ ). The remaining 38 students continued to participate in inquiry-based teaching (the ‘continuing’ group;  $n = 38$ ). An additional 27 low-achieving students from

other traditional teaching classes were transferred to the inquiry-based classes (the ‘transferred in’ group;  $n = 27$ ).

As with the studies discussed earlier in this section, the inquiry-based intervention was based on the NIB (Tsai et al., 2007). Activities such as demonstrations, discussions, experiments, challenging activities and take-home exercises were incorporated into each of the curriculum topics. Both quantitative and qualitative methods were used to collect data on the impact of the approach. Questionnaires were included in each survey: the SMTSL, the “What Is Happening in Class?” learning environment questionnaire (WIHIC, see Aldridge & Fraser, 2000; Fraser, 1998) and the self-developed “Perceptions Toward Inquiry Ability” (PTIA, Cronbach’s  $\alpha = 0.86$ ) questionnaire for measuring students’ perceptions of their own inquiry abilities. These questionnaires were administered at the beginning of the first semester and second semester (immediately after the class division) and at the end of second semester, that is, as pre-, interim-, and post-questionnaires. All the data were analysed using repeated measures and Scheffé’s comparison. Qualitative data were collected through semi-structured and informal student interviews and classroom observations.

Research findings revealed that students’ motivation in the transferred out-group (high achievers), their SMTSL, WIHIC, and PTIA increased significantly in the interim test, but, unfortunately, dropped significantly in the post-questionnaire one semester after they had transferred to the traditional teaching class. The continuous group students’ learning SMTSL and PTIA decreased slightly in the interim questionnaire but then increased again in the post-questionnaire. While their WIHIC did not change from the pre-, to the interim and post-questionnaire, for the transferred in-group, their SMTSL, PTIA, and WIHIC scores increased from the interim to the post-questionnaire; however, these findings were not statistically significant. The findings, therefore, indicated that inquiry-based teaching appeared to enhance the learning motivation of students of different achievement levels, but at differing rates. In addition, both high- and low-achieving students responded positively to their learning environment as a result of the inquiry-based learning. High-achieving students adapted to inquiry-based instruction faster than low-achieving students. The results from the transferring out-group also indicated the detrimental effect of traditional teaching on students’ learning motivation and their perceptions of their inquiry abilities.

Another study by Ling (2013) incorporated scientific games into guided inquiry-based instruction nine times during one semester with a class of 25 eighth-grade, low-achieving students. The SMTSL was administered before and after the study. In addition, she collected students’ scores from three monthly examinations, and administered a pre- and post-test to investigate students’ understandings of specific scientific concepts taught in the inquiry-based instruction. An example of the scientific concepts test is

If we divided a material into two parts, for the part with large volume, its Specific Heat will be (A) smaller than the small volume part, (B) larger than the small volume part, (C) the same as the small volume part. Please circle the correct choice and then write down your reason.



Eleven students participated in semi-structured pre- and post-interviews. Class video-recordings were also collected and analysed in relation to the students' in-class participation. The findings of this study revealed that these low-achieving students' SMTSL scores in the post-test were significantly higher than in the pre-test ( $p < 0.001$ ). However, there was no significant increase in the T scores in the three-monthly examinations. These students improved their scores in the science concept part of the post-test. At the beginning of the study, low achievers were very passive when it came to participating in the class activities. After one semester's treatment, however, they changed their attitude from being passive observers to actively participating in the inquiry activities. They also showed their enthusiasm about winning the competition game-like activities in class.

### *Inquiry-based instruction and problems faced in implementation*

Chen (2011) used an action research approach to implement inquiry-based instruction to improve low achievers' learning. He collected data from various sources: classroom video recordings, students' and his own reflective journals, students' worksheets, and interviews with students. Chen applied NIB inquiry-based instruction in his study. The findings showed that the challenges he faced during the implementation of the intervention included worksheet design, students' attitudes, and reticence in terms of embracing the inquiry-based instruction, classroom management problems, pressures related to students' expectations about preparing for high-stakes assessments and group cooperation issues. Solutions that Chen used to address these challenges included integrating curriculum content with students' everyday experiences, increasing the use of hands-on activities, explicitly outlining behavioral expectations of the activities, training group leaders to conduct group activities and discussions, selecting activities and tasks with appropriate difficulty levels for students, increasing the teacher's guidance, using questioning to guide group activities, helping students to master their understanding of key concepts before the monthly tests, and seeking support from school administrators, experts and colleagues. After one semester of action research, the findings showed that the students had improved their learning attitudes and were more willing to learn difficult concepts and take a more active role in clarifying their conceptual understandings, and that they reported increased satisfaction and confidence in relation to their learning.

Tan (2012) also adopted an action research approach and implemented the 5E approach with a seventh-grade class ( $n = 30$ ) during a semester of biology lessons, investigating the impacts on students' science learning motivation. The SMTSL was administered at the beginning and end of the semester. In addition, she videotaped her classroom teaching, kept a journal about her teaching, collected students' worksheets, and interviewed nine selected students. When Tan used action to implement inquiry-based instruction, she conducted two cycles of her action. In the first cycle, she faced a major problem – namely, that the students did not know how to use cooperative learning strategies to conduct inquiry activity and discussion. Tan used the following strategies to solve the problem. First, she used

heterogeneous grouping strategies to group the students; thus, students with different abilities could help each other in a group. Second, she adopted questioning strategies to guide students to confirm and direct their inquiry design and to train them to examine their design using scientific methods. After implementing these strategies, the students adapted to the inquiry activities, and all group members increased their engagement.

In the second cycle of the project, Tan (2012) faced the problem that most of the lab work and discussion were dominated by higher achievers or lively students. The solutions Tan used are as follows: she established a friendly environment and encouraged and praised all students to encourage them to express their ideas. After class, she talked to individual students to understand their learning problems to help and encourage them. Finally, she designed a duty sheet for group members to fill in so that each group member could share responsibility for the group work. The second problem faced was that some middle and low achievers copied the worksheets from their peers, or they could not complete the worksheets on time. The solutions Tan used are as follows: She taught the students how to observe and how to think logically. She also used encouragement to replace punishment and guided the students to attribute their failure in the science activities to not putting in enough effort rather than to their lack of ability. Tan tried to use multiple content, task-oriented, situation-oriented, and daily life oriented activities to enhance the students' learning motivation. Finally, Tan adjusted the difficulty level of the worksheets to fit the students' level, and permitted the students to use drawing to express their thoughts. As a result of these actions, the students recognised that they had the ability to complete the worksheets and appreciated that the worksheets were designed to examine their ability. Therefore, they were willing to complete the worksheets.

In the second action cycle of the project, Tan (2012) faced the problem that she could not control the exact time to implement the inquiry-based activities; therefore, the curriculum progress was delayed. The solutions used by Tan were as follows: First, at the beginning of the activity, she established clear rules and a scoring system, using the students' sense of honor to push them to study hard and actively engage in the activities. Second, she gave worksheets ahead of conducting activities; therefore, the students could understand and prepare the content of the inquiry activity; this way, she could save time spent providing explanations, and the students could prepare all of the materials beforehand could use time wisely in the class setting. The outcomes of these solutions were that the students became more organised and disciplined in conducting activities in a timely manner. The second problem faced is that the students were too shy and timid to present their results in front of the class. Tan's solutions were to demonstrate procedures of group presentation to all students, and to guide the students to use multiple ways to present their results. The second strategy is that when students faced difficulty in their presentation, the teacher would give them hints or help; this could save the students from feeling frustrated. As a result of these strategies, the students could imitate scientists to conduct cross-group discussion; meanwhile, the students could express their ideas in various ways.

Finally, Tan summarised her inquiry-based action research as consisting of three parts: inquiry-based activities, learning environment, and, finally, instructional strategies. These solutions are useful for future science teachers to practice.

The findings indicated that the students' motivation scores increased significantly, as did their scores related to self-efficacy, active learning strategy, and learning environment stimulation. Tan (2012) also found that inquiry-based teaching can enhance the motivation of students of different achievement levels. In terms of the students' learning outcomes, she found that the high achievers liked learning science more, and had confidence in their ability to accomplish the inquiry activities. In addition, the high achievers appreciated how science knowledge learned in class can be applied in daily life, and they became aware of the meaning of learning science and would take an active role in learning science beyond the science class. The middle achievers were attracted by the inquiry-based learning environment. They established effective learning strategies during the inquiry processes; they would ask the teacher or group members' questions and used what they learned to accomplish their tasks. They started to recognise their ability to accomplish inquiry activities. As for the low achievers, their willingness to learn science increased during the cooperative learning process, and they knew how to ask for help to reduce their learning pressure and to learn problem-solving abilities gradually and believed in their ability to accomplish their tasks.

## Conclusions

The review in this chapter has highlighted the various inquiry-based learning outcomes, problems, and solutions in implementing inquiry-based instruction in classroom settings, and teachers' learning inquiry-based instruction. Several studies specifically showed that students of different abilities or motivations could all benefit from inquiry-based instruction. The earlier literature also shows that both science educators and teachers have found various ways to implement inquiry-based instruction in classroom settings and to overcome obstacles. In response to the question, "Will inquiry-based instruction fade away and be replaced by other new teaching approaches?" we believe that as long as we continue to be receptive of new visions for science education, such as STEM (NRC, 2011), the inquiry-based practice will continue to dominate the elementary and secondary science curricula in the future. In 2018, a new curriculum which focuses on grades 1–12's continuous curricula will be implemented in Taiwan. This new curriculum also focuses on inquiry-based practice in teaching science (Hung & Fan, 2015). Therefore, inquiry-based instruction will continue to be an emphasis in the Taiwanese science education arena.

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# 7 Teaching values and life skills using reversed analogies in school science

*Kok Siang Tan*

## Introduction

Three domains of learning have been described, namely the affective domain, the cognitive domain, and the psychomotor domain (Bloom, 1956; Krathwohl, Bloom, & Masia, 1999). School curricula are typically designed and implemented around these domains of learning (Anderson & Krathwohl, 2001; Marzano, 2008). When it comes to assessment of learning, especially in high-stakes national examinations, the focus is usually on the cognitive and psychomotor domains. This may result in less emphasis on affective learning, which is a critical part of most school curricula. However, affective learning and assessment have been gaining attention in recent years (Izabela, 2010; McCoach, Gable, & Madura, 2013; Ministry of Education [MOE], 2017a, 2017d; Pierre & Oughton, 2007; Popham, 2010). For example, the Singapore school science curriculum, which has always emphasised a holistic approach to the learning of science, and the science syllabuses of the Singapore-Cambridge General Certificate of Education Examinations have clear descriptions of desired learning outcomes covering all three domains of learning (MOE, 2017a; SEAB, 2017).

Pen-and-paper assessment of school science content and skills in most national assessment curricula often emphasises testing students on their competencies in the cognitive and psychomotor domains. In the Singapore science syllabuses, these are described in the areas of “knowledge with understanding”, “handling information and solving problems” and “experimental skills and investigations” (Science Syllabus, SEAB, 2017, pp. 3–4). In recent years, the Singapore government has been actively supporting affective learning through the introduction of Character and Citizenship Education and Values Education across the entire school curriculum (Heng, 2011; MOE, 2017a, 2017b). Despite more attention being given to affective learning, parents, teachers and students remain concerned about doing well in national science examinations because they continue to consider having good examination results as the main criteria for entrance into tertiary institutions in Singapore and overseas (Coulby, Jones, & Harris, 1992; Keeves & Watanabe, 2003).

The focus of this chapter is on student learning in the cognitive and affective domains. The aim is to share a potentially impactful pedagogy that can integrate student learning experiences in both the cognitive and affective learning domains

during the same science lesson. The pedagogy, called ‘reversed analogy’, supports the infusion of affective learning opportunities into the school science curriculum without significantly changing how science is taught in class. The discussion of the use of this pedagogy is not based on specific empirical studies, but on classroom trials by a primary school teacher (Tan & Santhanasamy, 2012) and two secondary school teachers (Tan, Heng, & Tan, 2013) in Singapore. These lesson ideas were implemented between 2011 and 2013, a two-year-long collaboration with the author, who is also a science educator and a qualified secondary school science teacher. The teachers had reported impactful feedback from their classroom lesson experiences on the use of this pedagogy. The objective of this chapter is therefore to share the teachers’ ideas and their students’ learning experiences in the school science lessons.

### **The importance of the affective domain of learning in the school curriculum**

The affective domain deals with students’ learning attitudes and their motivation to learn (Ellis, 2001; Martin & Briggs, 1986; Popham, 2010). Giving the affective domain a significant focus in the school curriculum is important for the holistic development of the students. However, some scholars and educators have noted that these domains are often considered separately in curriculum planning and teaching in schools (Aspin & Chapman, 2007; Krathwohl et al., 1999; Popham, 2010). Martin and Briggs (1986) attributed this segregation to the schools’ needs for planning and implementing their curricula, and the need to be accountable for students’ learning progress and achievement. It is also well documented that assessing affect is more difficult than assessing content knowledge or skills-based performance. This difficulty arises because of the subjective nature of learning in the affective domain, whereas assessment in the other domains may be done more objectively and can hence provide a more reliable account of the students’ performance (Mertler, 2003; Oakland, 1997). Affective learning opportunities are therefore often missed or covered superficially in school science curricula (Chamberlin, 2012; Olatunji, 2013).

We live in a modern world characterised by an increasingly connected and growing base of knowledge. Often there are unpredictable events that impact large groups of people everywhere. For example, the world has been experiencing frequent tsunamis and earthquakes. There are new infectious diseases surfacing, such as Zika, SARS, MERS, and Ebola, and there are threats from global environmental pollution and terrorism. These situations cannot be understood as packages of discrete information and knowledge. Whether as experts or as ordinary citizens, we now need to be competent in, or at least comfortable with, a range of skill sets in order to understand and deal with these issues. We have to make meaningful connections of knowledge and processes in the different domains and disciplines of learning in order to survive well in this modern world (Gardner, 2006; McTighe, 2010). Thus, schools need to better prepare students for the kind of world they will be living in after their graduation by helping them

make meaningful connections between the various learning domains and subject disciplines.

Affective learning concerns the socio-emotional states of learners. Picard et al. (2004) explain that for students to internalise their learning they need to have a deep emotional link with what they are learning about. Researchers such as Martin and Briggs (1986) and Valiente, Swanson, and Eisenberg (2012) have extensively studied this link. They found that if learners can associate their learning with an emotionally linked event or situation in their lives, then they might be more likely to embrace positive social values and practise life skills associated with these lessons. In school, learning is often content-based (with subjects like science, geography, history, and language) or focused on mastering skills (like playing games in physical education and performing in fine arts, music, and dance). If students' learning experiences in these content and skills-based areas can be emotionally linked to their everyday life experiences, then there is a good likelihood that they may understand and embrace positive social values such as honesty, respect, care, and concern. They may also acquire good personal habits such as being responsible and punctual, and develop effective life skills such as good teamwork and personal organisation skills. In other words, if science lessons can help students understand and emotionally link the science concepts and skills they learn in class to the importance of positive social values and lifeskills, they could become more motivated to learn science and embrace the desirable social values and attitudes in life (Gardner, 2006; MOE, 2017b; OECD, 2009).

### **Developing students' value awareness during science lessons**

Interest in the importance of values in and about science education has increased in recent decades (Corrigan, Dillon, & Gunstone, 2007; National Academy of Sciences, 1997). The Singapore Science Curriculum Framework, which adopts scientific inquiry as the focused pedagogical approach, also has strong components of affect (MOE, 2017c). The Framework suggests that science teachers should lead students in the inquiry-learning process ("teacher as the leader of inquiry", MOE, 2017c, p. 1), while their students are expected to be developed as effective inquiry learners of science ("student as the inquirer", MOE, 2017c, p. 1). Supporting this inquiry approach are the science content and process skills that students learn at school as well as the affective learning components of positive attitudes and motivation to learn science. In Singapore, National Education, Character and Citizenship Education and Values Education have also been infused across all learning areas of the curriculum. These are further supported by the introduction of the 21st Century Competencies Framework (MOE, 2017d) and the Applied Learning Programmes (Science Centre Singapore, 2017), which were introduced to support STEM education in Singapore schools (EduMatters, 2014; MOE, 2017b; Science Centre Singapore, 2017). These whole-school curricular programmes are currently being actively implemented in schools with strong support from the government.



Specifically in school science, some teachers in Singapore have also been trying to infuse affective elements of learning into their routine science lessons. Three teachers, one primary and two secondary, collaborated with the author to implement an integrative pedagogy, known as “reversed analogy”, to enhance students’ surface awareness of positive social values during classroom science lessons (Tan et al., 2013; Tan & Santhanasamy, 2012). This collaboration is not part of the government’s programme, but a grassroots effort by these teachers and the author to provide a feasible teaching approach to help support student learning of science in both the cognitive and affective domains.

Compared to other learning domains, teaching and learning issues in the affective domain are less extensively described and studied in the literature (Gano-Phillips, 2009; Koballa, 2016). Olatunji (2013) attempted to present affective learning within two schools of thought. The first describes affective learning characteristics (values, moral, ethics) as being found outside the human life experience. These characteristics, according to Olatunji, could be “found in divine inspiration and the wisdom of the elders over the years” (p. 97). The second school develops an understanding, acceptance and practice of values and affective characteristics through critical analyses of human experiences, either as individuals or as groups. This may involve stage-wise reflective interaction with the environment or community to develop the values, beliefs or practices that are then applied in subsequent life experiences. This second school of thought is applicable in school science, which encourages learners to observe their surroundings and to reflect on how the environment and the community interact and connect to ensure the continuing survival and well-being of life on Earth.

The lesson ideas from these three teachers that are shared in this chapter all involved students making connections between two separate learning experiences, that of learning a science concept and discussing an affective characteristic (a value or life skill). The pedagogy employed to help students make the links between their learning experiences in school science and their everyday lives is the use of analogy, a well-cited pedagogy in science education literature (Harrison & Coll, 2008; Harrison & Treagust, 2006; Orgill & Bodner, 2004).

### **Using reversed analogies to support learning in the affective domain**

The use of analogies in science education to enhance students’ understanding of concepts and their attitudes towards learning science has been widely advocated by science educators (Aubusson, Harrison, & Ritchie, 2006; Harrison & Coll, 2008). While the literature includes robust debates on what constitutes an analogy and if the use of analogies in science lessons is indeed effective (Harrison & Treagust, 2006; Orgill & Bodner, 2004), these issues are not explored in detail here. Rather, the focus is on sharing how some Singaporean teachers used analogies to raise students’ awareness of values and life skills during their science lessons. The sharing will show how implemented and suggested lesson ideas may be used to

effect a transfer of learning from the analogue or base (that is, the science concept students learn in class) to the target (a positive social value or life skill students are expected to become aware of) during a typical science lesson.

Venville (2008) describes an analogy as “a quick and interesting way to explain non-observable science objects, such as atoms, and abstract processes” (p. 23). Similarly, Wilbers and Duit (2006) define analogy as “a similarity between two domains, commonly called the ‘base’ and ‘target’” (p. 38). The ‘base’ may also be referred to as the ‘analogue’. Thus, the teacher will often use a familiar, everyday experience (the base or analogue) to help students understand a science concept or master a process skill (the target) (Figure 7.1).

An example of an analogy to describe the Greenhouse effect is that of a car left in the sun with the windows wound up. In the Greenhouse effect, heat from the sun is trapped under a gaseous layer in the Earth’s atmosphere, thus raising the average air temperature (the concept of the Greenhouse effect is referred to as the target). Similarly, the car’s interior remains hot even after the sun has set because the glass windows slow the movement of heat back out of the car (this routinely observed situation is referred to as the base or analogue). Another example is the commonly used lock-and-key model (the base or analogue) to explain the specific nature of enzyme reactions (the target).

By reversing the analogy (‘reversed analogy’), a science concept is used instead of a daily life experience as the analogue to illustrate a positive social value. In other words, the teacher may teach students a science concept or a process or laboratory skill and then use this new knowledge or skill as the ‘reversed’ base or analogue to illustrate a familiar everyday life experience relating to a positive social value or effective life skill (the ‘reversed’ target). The aim is to raise students’ awareness and enhance their understanding of this value or life skill by drawing their attention to the similarities between this value or life skill and the science concept or skill they have just learnt in class (Figure 7.2).

An example of how a reversed analogy is used in a science lesson would be to teach students about how carbon atoms are subjected to extremely high temperatures and pressure deep in the Earth over a long period of time until these atoms eventually become a large diamond molecule. This large and rigid

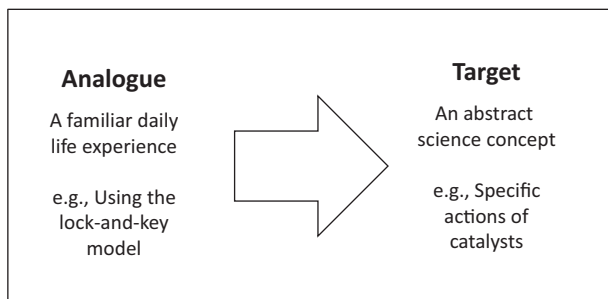
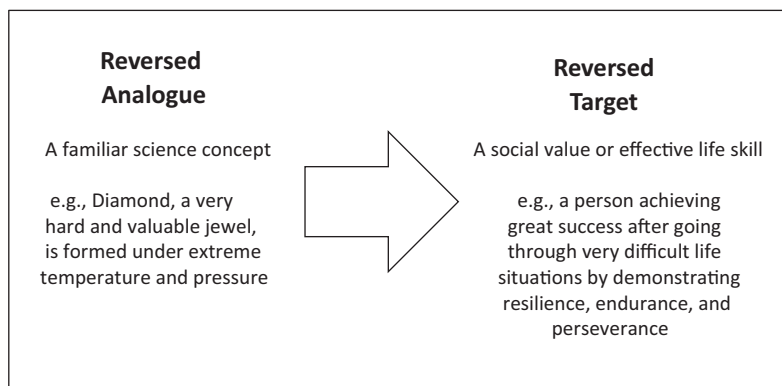


Figure 7.1 Use of analogy in school science



*Figure 7.2* Reversed analogy in school science

molecular structure is well known for its properties of being one of the hardest substances and also for being a highly valued and sought after gemstone. Thus, like the extreme conditions, the carbon atoms are exposed to, we may be faced with harsh or challenging conditions in life, but if we persevere and manage these challenges at work and overcome the stress in life, we can eventually develop a strong and resilient character, much like the way in which the carbon atoms form a diamond molecule. Thus, the process of diamond formation can then be used as the base (or ‘reversed’ analogue) to illustrate the human character of resilience or perseverance (the ‘reversed’ target). The word ‘reversed’ is used because, in the usual sense of an analogy, the analogue refers to a common, everyday event or experience, while the target is the taught science concept or skill. In order to raise student awareness of values and life skills, the order of the analogy is thus ‘reversed’.

Table 7.1 shows some of the lesson ideas regarding the use of reversed analogy that were actually used by the teacher collaborators in their respective primary and lower secondary school science lessons. Table 7.2 provides some suggested high school and college chemistry lesson examples that have either been implemented or suggested by the author and the three science teacher collaborators. Finally, Table 7.3 consists of a list of other possible teaching ideas which may be implemented in a typical secondary school science lesson.

### **Benefits and limitations of the use of reversed analogies**

The teacher collaborators reflected on the strengths and limitations of the use of reversed analogies in their science lessons. The more significant benefits cited include the following: (1) a continued focus on promoting the teaching and

Table 7.1 Integration of cognitive and affective lesson ideas in primary and lower secondary school science

<i>Science Focus (Idea/ Concept/Skill Taught)</i>	<i>'Reversed Analogue' (Key Concept/Skill; Conceptual Question)</i>	<i>'Reversed Target' (Question in Affective Domain; Affective Element of Learning)</i>
Use of plumb line (primary / lower secondary Tan & Santhanasamy, 2012)	What is a plumb line used for? [To check if an object is upright by holding a plumb line against it.]	Who are the 'plumb lines' in your life? [Positive role models in your life whom you respect and admire most and whom you aspire to emulate.]
Centre of Mass (or Gravity) (Lower secondary science)	"Centre of mass is a well-defined point at which the entire mass of the system can be considered to be concentrated" (Newman, 2008, p. 145) [An irregularly shaped cardboard can be made to balance when its centre of mass is placed on a fingertip.]	Have you found the "Centre of Mass" in your life? [The 'centre of mass' may be used to illustrate the focus in one's life. If we have identified our focus – be it a passion, a loved one, or a belief – it would have kept our lives balanced and happy. Changes in our lives can shift this focus, much like adding a weight to a cardboard being balanced on a fingertip.]
Functions of tree roots (primary and lower secondary science)	What are the functions of roots? What may happen to a tree if its roots have been severed? [To anchor the plant or tree firmly in the soil, and to help the plant or tree absorb water, nutrients and minerals salts.]	What may happen to if you have severed all your ties and relationships with loved ones and friends? [Forging close relationships with loved ones and friends gives you the support you need to continue to grow emotionally.]

learning of science concepts in class, (2) a "spill-over" effect between the cognitive and affective segments of the lesson, (3) it does not take long to prepare for the affective learning activities, and (4) the teachers did not feel compelled to teach values in class. These benefits are significant because teachers, parents and school administrators will be convinced to support the use of reversed analogies as an impactful affective learning pedagogy in class.

Table 7.2 Integration of cognitive and affective lesson ideas in secondary school and college chemistry lessons

<i>Chemistry Lesson (Idea/Concept/Skill Taught)</i>	<i>'Reversed Analogue' (Key Concept/Skill; Conceptual Question)</i>	<i>'Reversed Target' (Question in Affective Domain; Affective Element of Learning)</i>	<i>Comments</i>
<p>Strong and weak acids (Secondary science, Tan, Heng, &amp; Tan, 2013)</p> <p>A 2-cm piece of magnesium ribbon is dropped into a beaker containing 50 ml of hydrochloric acid (1M, a strong acid), and a similar piece into another beaker containing 50 ml of ethanoic acid (1M, a weak acid).</p>	<p>In which beaker would the piece of magnesium ribbon be used up faster?</p> <p>[The magnesium ribbon in the hydrochloric acid will react faster so it will be used up first. Being a strong acid, it will fully dissociate to form hydrogen ions to react with the magnesium. Ethanoic acid is weaker and partially dissociated, thus producing fewer hydrogen ions.]</p>	<p>If the piece of magnesium ribbon represents the monthly allowance your parents give you, which reaction characteristic (that of hydrochloric or ethanoic acid) would best represent the way you use the money?</p> <p>[The spendthrift students would probably identify themselves with the strong acid reaction.]</p>	<p>Awareness is raised about how students use their monthly allowance. The teacher need not suggest which way is better, although they may also advise students to use their allowance wisely and to save some money for so-called rainy days.</p>
<p>Rate determining step in multi-step reactions (modelling). (College level, Jacobsen, 2004).</p> <p>Students time the rate of water (200ml) flowing out of each of three cups. Each cup has one, two or three holes in their bases. Then students determine the overall flow rate by stacking the three cups in different combinations (e.g., 1-2-3 holes, or 2-3-1, etc.)</p>	<p>“What conclusion can you make from your observations about a multi-step reaction?”</p> <p>[The overall reaction rate is determined by the rate of the slowest reaction.]</p>	<p>(1) Compare the effectiveness of doing work alone and as a group.</p> <p>[“More hands lighter work”]</p> <p>(2) How do we improve the productivity of a team?</p> <p>[A team’s productivity is most likely affected by the slowest member (weakest link) hence team members should help him or her improve.]</p>	<p>Awareness is raised about teamwork:</p> <p>(1) If each hole in the cup represents an individual, with more holes water will flow faster.</p> <p>(2) If each cup represents an individual, when the cups are stacked up, the combined rate of water flow will be the rate of the water flow through the cup with the least number of holes. Thus, to raise team productivity we need to help the slowest team mate improve.</p>

Table 7.3 Suggested lesson ideas on the use of reversed analogies for secondary school science

<i>Science Lesson (Concept/Skill)</i>	<i>'Reversed Analogue' (Key Concept/Skill taught)</i>	<i>'Reversed Target' (Possible Affective Element of Learning)</i>
Adaptation of plants ( <i>Biology</i> )	The tendrils of creepers growing on fences to reach out for sunlight.	Patience, adapting to life's situations as we mature.
Phototropism and hydrotropism ( <i>Biology</i> )	The shoots of germinating seedlings will have its shoots grow towards sunlight and the roots grow toward the ground for water (regardless of the orientation in which the seedling is placed).	Perseverance and determination to reach life goals (using all your available resources effectively and wisely) or you need to grow in the right direction to be successful.
Elasticity ( <i>Physics</i> )	Materials like a metal spring or a rubber band may return to their original shape after stretching. However, once the elastic limit is reached, they may become permanently deformed or snapped, like when a guitar's strings are over-tightened.	Stress management. We need to have some stress to be creative and productive (just like a well-tuned guitar) but too much stress is damaging (like an over-tightened guitar string that snapped).
Newton's Third Law of Motion ( <i>Physics</i> )	For every action there is a reaction which is equal in magnitude and opposite in direction.	Choices have consequences.
Volatile liquids ( <i>Chemistry</i> )	Volatile liquids have low boiling points and can easily catch alight. This is why it is important to never heat a beaker of alcohol with a Bunsen flame as the alcohol vapour can ignite and cause a fire.	A person with a short temper is like a volatile liquid. At the slightest provocation, this person can burst into a feat of anger. When encountering such persons, it is best not to be provocative.

The first benefit of using this pedagogy is that the main focus of the science lesson is still about ensuring that students learn and understand science so that they can be well prepared for the relevant assessments. In a typical 60-minute lesson (during the collaboration), less than 10 minutes was spent on an affective learning activity. Parents and school administrators can therefore be assured that the affective learning segment of the lesson will not dilute the teacher's efforts to prepare the students to sit for the national examinations.

The second benefit refers to the 'spill-over' effect between the cognitive and affective learning segments of the lesson. While teaching students science concepts, students are generally attentive and serious. They may also enjoy the challenges and fun that come with the usual science lessons. When the affective learning task is seamlessly introduced, the students were often observed by the teacher collaborators to remain as active, energetic, and enthusiastic about the affective learning task. Hence the teachers described it as the 'spill-over' effect. One of the collaborators, the primary science teacher, observed that students who had never participated in such integrative lessons before found the transition from a conceptual lesson to an affective learning activity refreshing and unique (Tan & Santhanasamy, 2012). Another collaborator, a secondary science teacher who taught a lesson comparing the rates of reaction between the metal magnesium and a weak or strong acid, noted that students were able to draw appropriate comparisons, not only about the chemical reactions but also how these reaction characteristics illustrated their spending habits. She noticed that students wrote interesting comments about their spending habits in response to the task on the worksheet that asked them to comment on how the reactions could illustrate how they spend their pocket money. For example, some students wrote, "I spent (my) money very quickly" (referring to the fast reaction between magnesium and a strong acid) and "We should always save some money in case of financial troubles" (referring to the leftover magnesium metal in the reaction with a weak acid) (Tan et al., 2013, p. 16). These students' statements are interesting because they are now using their observations made in a science practical lesson to describe how quickly or wisely they had been spending their pocket money. It is a clear indication that the students had become more aware of their spending habits as a result of the links made to their observations of magnesium reacting with an acid in the earlier science lesson.

The teacher collaborators also agreed that the time spent planning and preparing for the affective learning activity was minimal. The activity is typically short, usually a few minutes for class discussion or a short worksheet task reflecting on the new concept or skill learnt. In fact, the worksheets used in the secondary science lessons were the same as those used by the collaborating teachers in previous years. The teachers merely appended a short affective learning task, for example, space for the students to write down how their observations of the reaction changes may illustrate their spending habits.

The final benefit cited by the teacher collaborators is the comfort level science teachers would have if they use reversed analogies to raise students' awareness of social values and life skills. They felt it was easier for teachers to raise student awareness through the use of reversed analogies than to explicitly tell students

what is right or wrong about their social behaviors or attitudes (Tan et al., 2013; Tan & Santhanasamy, 2012). Thus, teachers are unlikely to feel compelled to teach values in class. Instead, they saw it as an “affective teachable moment” in their science lesson. They were merely facilitating the students’ thinking, through the affective activity, by creating student awareness of the importance of positive social values and effective life skills.

However, the teachers also raised some limitations and concerns relating to the use of reversed analogies. Firstly, not all science concepts and laboratory skills may be suitable to be used as analogies to illustrate values and life skills. There should be clear similarities between the science concept and the value or life skill being compared. Otherwise, the teacher and students may feel awkward if they find the analogy irrelevant, and the affective message may appear to be forced upon the students. It would be useful for teachers to work with colleagues to identify possible and relevant “affective teachable moments” in the science curriculum. They can also seek the advice of experienced academics (for example, science education professors) or professionals (such as school counselors, educational psychologists or science curriculum specialists) for their views on the relevance or suitability of the specific reversed analogies they intend to use in their science lessons.

Teachers also need to be creative when attempting to use reversed analogies. Care should be taken when trying to make appropriate connections between the science concepts or laboratory skills and the positive values or life skills. Not all teachers are adequately or professionally trained. Some may not be emotionally ready, competent, or articulate enough to conduct such lessons. Thus, there could be adequate and appropriate training opportunities for teachers to help them work as a team to discuss and try out the learning activities. With professional and peer support, teachers would be more encouraged and ready to use the pedagogy.

The three collaborators are all experienced school science teachers. One of the secondary science teachers has at least three years of teaching experience, while the teaching experience for the remaining two teachers extends to more than a decade each. Based on their interactions with peers and school leaders, their most important advice to other teachers intending to use this pedagogy is to ensure that the science concepts and skills should be accurately and appropriately taught first before attempting to use reversed analogies to bring students into the affective learning domain. This is a valid concern since, as science educators, the author and his academic colleagues are also aware that misconceptions could arise when students are overwhelmed with additional information in a science lesson, especially with the academically weaker students. They are worried that students may become confused by the introduction of values and life skills after learning the science concepts. Hence, teachers will need to know the students well to decide if this pedagogy may be effectively applied to them.

## **Conclusion**

Schools are expected to produce well-rounded graduates who are not only knowledgeable and skillful in science-related work but also compassionate and sensitive to the needs of the community and the environment they live in.



A holistic approach involving the three learning domains, namely, the cognitive, psychomotor and affective learning domains, is thus necessary to develop students to be competent in knowledge, skills, and attitudes. This chapter sets out to share how school science lesson ideas can help support student learning in the affective domain. The collaborative efforts between the author, a science education academic, and the three school science teachers resulted in the development and implementation of the pedagogy, referred to as ‘reversed analogy’. This pedagogy is used to integrate science concepts learnt with affective learning opportunities during science lessons. The teacher collaborators in this developmental effort also found several benefits in using this pedagogy such as the minimal preparation time and the comfort level of teachers applying the pedagogy in class. Moving forward, science teachers and education researchers could be encouraged to further develop and evaluate the effectiveness of more lesson ideas to integrate student learning across the three domains, especially with the inclusion of the affective domain. It is through their exposure to integrative learning experiences in school that students may graduate better prepared to deal with problems and challenges in the world of work, and at the same time more confident in their ability to contribute positively to society.

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# 8 The influence of group work on students' science learning in Hong Kong primary schools

*Dennis Chun Lok Fung*

## Introduction

By the late 20th century, organising group work among students had become an increasingly popular strategy in many Western classrooms, especially in the area of primary science education (Harlen & Qualter, 2004). In Hong Kong, group work has played a minimal role in educational policy over the last three decades, and important blueprints associated with education reform seem to have ignored the pedagogical concept of group work. More importantly, even though group work is suggested in individual school curricula, most primary school teachers perceive it merely as a 'seating arrangement' (i.e., groups of students being seated together) instead of a teaching pedagogy, whereby students in effect are led by teachers in learning (Dimmock & Walker, 1998). In this way, so-called group work has made little pedagogical difference to the traditional practice of whole-class instruction. Furthermore, according to the Confucian-heritage culture prevalent in Hong Kong schools, students are viewed as passive, unwilling to express ideas, and reluctant to cooperate (Murphy, 1987). The majority of students prefer individualistic learning in the classrooms, where the pedagogic model is often described as 'instruction-practice-feedback' (Kennedy, 2002; Stevenson & Lee, 1997). They perceive their classrooms to be extremely competitive and isolating, while their teachers usually maintain a high degree of control through direct teaching (Leung, 2001; Morris, 1985).

In light of the previous context, this chapter first introduces the background to and emergence of group work in Western classrooms before discussing the implications of group work for students' science learning with reference to recent empirical findings (e.g., Galton & Pell, 2009; Webb & Mastergeorge, 2003). The chapter then reports on a qualitative research project that investigated the effectiveness of whole-class teaching and group work in two Hong Kong primary schools. By evaluating the results of that project, the chapter seeks to illustrate the efficacy of group work in further facilitating primary students' science achievement in Hong Kong, although it is recognised that Hong Kong students have achieved consistently high scores and occupied a favourable position in TIMSS since 2003 (i.e., ranked fourth, third, ninth and fifth in 2003, 2007, 2011 and 2015, respectively).

## Literature review

### *The emergence of group work*

In the last century, studies on and investigations into cooperation date back to the 1920s, when the ideology behind group work started evolving (Williams & Duch, 1996). However, the formal and strategic applications of group work did not begin until the late 1960s, when Calvin D. Crabill, a mathematics teacher in a US high school, thought of a new idea to keep his students' attention and to solve the difficulty of assessing students at their desks. Facing the challenge of small, over-crowded classrooms, each containing more than 60 students, Crabill decided to teach students in groups and assign them joint activities. After a successful period of practice, he came to the conclusion that group work presented an applicable solution to the persistent problems of lack of motivation and attention to learning (Crabill, 1990). Following Crabill's illustration of the practice of group work, ideas such as 'small-group learning' or 'small-group teaching' started to emerge in the field of pedagogical research during the late 1960s (see Barham, 2002, for further details). In the United Kingdom, various forms of collaborative group work have been implemented (Davidson, 1990; Reynolds, 1994). For example, ORACLE (Observational Research and Classroom Learning Evaluation), a UK-based project incorporating descriptive observational approaches to investigate primary classroom activities, commenced in 1975 but is still making a significant contribution to group work scholarship (Gill & Remedios, 2013).

### *The pedagogical advantages of group work*

In the literature related to group work practice (e.g., Lou et al., 1996; Stoll et al., 2003; Webb, 1989, 1991), there is strong evidence that group work is associated with better academic performance. Nearly four decades ago, Johnson and Johnson (1979) investigated the impact of collaborative, competitive and individualistic learning experiences on student academic achievement, finding that collaborative learning (i.e., group work) is superior to competitive and individualistic study approaches in promoting higher academic achievement. More importantly, the results held not only for mixed-ability collaborative learning groups but also for students identified as being more challenged academically. Consistent results were reported in studies examining the effects of the aforementioned three types of learning structures on different school-related tasks such as reading and arithmetic (Brewer, 1974; Garibaldi, 1979).

In fact, teaching science through a constructivist approach has become increasingly popular since the mid-20th century. Even though group-generated views are not necessarily internalised by every member of a group (Howe, Tolmie, Greer, & Mackenzie, 1995), collaborative group work has been found to enhance students' acquisition of science concepts and to encourage them to tackle those concepts at a higher cognitive level (Springer, Stanne, & Donovan, 1999).

Recently, science educators (e.g., Chin & Osborne, 2010; McNeill & Pimentel, 2010) have begun to place more emphasis on the critical role that teachers play in joint learning discussions, arguing that teacher prompts (i.e., open questions) can inspire divergent thinking and informed decision-making based on the solid knowledge that students acquire in science classrooms.

## **Research context and questions**

Although group work has been recognised as an effective teaching practice of education worldwide, it has been relatively underplayed in primary schools in Hong Kong (Galton & Pell, 2009, 2012). However, policymakers and scholars have more recently begun to perceive group work as not merely a teaching strategy but also as a revolution in the values and beliefs in the Hong Kong education system (Fung, 2014b). As a result, in 2007, the chief executive in Hong Kong announced the ‘Small-Class Teaching’ (SCT) policy in public-sector schools, which requires all primary schools in Hong Kong to gradually implement SCT in classrooms from the 2009–10 school year (EDB, 2008). In particular, the SCT policy was aimed at improving the quality of teaching and learning through a reduction in class size (from 38 to 25), reducing the dominance of teacher talk in the classroom, and facilitating more active student participation (Galton & Pell, 2009). The policy has been considered a prominent feature of the educational reforms implemented in Hong Kong over recent years.

Because the aforementioned SCT policy is relatively new, and investigations of group work in the Hong Kong context remain limited, very little research has been published in the past decade, and there is also a lack of empirical studies examining the influence of our Confucian heritage on group work in Hong Kong primary schools. Hence, questions related to the effectiveness of group work and its impact on Hong Kong students’ learning in primary science are worthy of investigation. As a consequence, the research questions driving the study reported in this chapter were the following:

- 1 What is the effectiveness of group work in enhancing students’ science understanding in Hong Kong primary schools?
- 2 What is the influence of group work on Hong Kong students’ learning style in primary classrooms?

## **Research methods**

### *Participants and research design*

The study reported in this chapter was conducted in two primary schools situated in the same district in Hong Kong. In the first instance, the schools were sent written invitations to participate in the project. Their formal agreement was

*Table 8.1* Quasi-experimental research design

	<i>Quasi-experimental Research</i>	
<i>Number of schools = 2</i>	<i>Each school (N~70) [Control Group N~35 and Experimental Group N~35]</i>	
Total participants (N~140)	Control Group (N~70)	Experimental Group (N~70)
Pedagogy	Whole-class Teaching Approach (N~70)	Group Work Approach (N~70)
Group Size	N/A	Around 7 students

obtained before the project commenced. From each school, two classes of Primary 5 (P5, fifth-grade) students participated. They were roughly 11–12 years of age. A total of around 70 students in each school were evenly distributed into the control and experimental groups. Two teachers in each school participated in the teaching intervention (see the following discussion for more detail). The schools shared many similarities, including academic standards and classroom organisation, and were among the top third of schools in Hong Kong. Therefore, in an empirical sense, the schools and their classes could be regarded as having similar ability levels.

In each school, one class of students was chosen to be the ‘conventional class’ while the second class was assigned as the ‘group work class’. In order to reflect an ‘authentic’ primary school context in Hong Kong, the reported research did not strive to adopt a pure experimental, but ecologically invalid, design (Wegener & Blankenship, 2007); instead, it employed a quasi-experimental design in which the former class was designated the ‘control group’ and the latter the ‘experimental group’ (see Table 8.1 for further information). In terms of research ethics, students were reassured that their performance in the intervention would not count towards their school examination scores and that they could withdraw from the programme without penalty at any time.

In principle, the major difference between the control and experimental groups was the instructional approach in the teaching intervention. Specifically, the students who were assigned to the control group learned science concepts through traditional, whole-class teaching. They studied in an independent manner and sat apart from each other, working on their own during the lesson. In contrast, instead of working individually like the control students, the experimental group students had the opportunity to conduct joint learning activities and group discussions using a collaborative approach. They sat together in groups of four to facilitate dialogic interaction and conduct collaborative reasoning practices.

### *The teaching intervention*

The intervention reported in this chapter was incorporated into a large-scale research project (Fung, 2014a) investigating a series of ten general studies<sup>1</sup> lessons in two Hong Kong primary schools. The research project contextualised the teaching of critical thinking and decision making through group work in the general studies lessons. In particular, the intervention introduced problem-solving activities, including discussions, debates, presentations, and reflection, into the content of the general studies curriculum. The teaching programme attempted to cultivate students' critical-thinking skills in order to argue, rebut, and provide evidence to support students' understanding of the concepts introduced in the lessons. Before the intervention, the participating teachers attended several training workshops in which they learned how to facilitate students' dialogic interactions and how to help students to identify the aims of the joint learning activities. They were also trained to engage students in collaborative discussions through an encouragement and reward system (e.g., by giving extra marks to the whole group) before acquiring the group work techniques to be adopted in the intervention.

More specifically, in Lessons 1 and 2, the students in both the control and the experimental groups participated in several 'ice-breaker' activities designed to introduce them to working with their classmates. This was particularly important for the experimental group students since they had to practice the collaborative skills (e.g., trust building and resource sharing) learned in the training workshops before they started working in groups. In these two lessons, the participating teachers also introduced the aims, objectives and implementation of the teaching programme.

In Lessons 3–8, the participating students started to apply thinking skills to answer questions related to the module, 'Science and Technology in Everyday Life' in the general studies curriculum.<sup>2</sup> The lessons not only provided students with opportunities to practise both evidence-based justification and the generation of critiques but also taught the ideas of meaning clarification. Specifically, the control group students learned and discussed science concepts as part of whole-class instruction, and the lessons were largely teacher-led. For example, the teachers facilitated individual presentations by students in the whole-class environment, reflective discussions, class debates and question-and-answer sessions, and they provided students with plenty of time to work individually on the questions (e.g., floating and sinking in water, see Appendix). The teachers carefully selected inspiring and well-justified responses to the questions. The students who constructed good pieces of work were invited to share their ideas in front of the whole class.

In contrast to the control group students, the students in the experimental group had opportunities to conduct joint argumentation during group work activities. In each group, the students were divided into 'for' and 'against' sides to debate topics based on the science questions. For example, the question



‘Does an object sink when it is small and heavy?’ was discussed. After the first round of debate, the students switched sides for another round of discussion to ensure that all students had the chance to present their ideas on both perspectives. Subsequently, the students in each group reached a consensus on the topic and presented their ideas to the whole class in turn. The teachers joined in the small-group debates, guiding students’ discussion and facilitating smooth dialogic interaction. During discussions, the students followed their ground rules and took an active role in the debates, thus avoiding the issue of ‘free-riders’.

The last two lessons of the intervention were aimed at consolidating the students’ understanding of the science concepts and obtaining student feedback on the teaching programme. The students were also required to engage in self-reflection on their performance and motivation regarding the learning tasks. Finally, the research team held evaluation sessions on the effectiveness of the intervention and the observations of students’ behaviour in the classroom activities for the participating teachers.

### *Data collection and analysis*

Two main types of qualitative data were collected in the study. First, classroom observations were conducted and audio-recordings were made of students’ individual presentations (for the control group students) and group debates (for the experimental group students). These provided evidence showing how students constructed their science understandings through individualistic and collaborative approaches. The audio-recordings also gave insights into the students’ engagement and motivation in particular science learning tasks. Second, focus-group interviews were conducted with one-sixth of the student participants and all teacher participants. Both sets of interviewees were asked about how they had performed in the intervention and about their preferences concerning the whole-class teaching versus the collaborative learning approach. As regards the data analysis, the audio-recordings (from the group debates, presentation, and focus-group interviews) were transcribed and then imported into NVivo™ (QSR, 2001) for holistic examination. The student dialogues and presentations were qualitatively analysed to answer the study’s research questions.

## **Results**

### *Student presentations and dialogues*

To understand students’ joint construction of science concepts during the teaching intervention better, four excerpts were randomly extracted from the audio-recordings of the group debates and individual presentations for further empirical investigation. In the first two extracts, the control and experimental group students are discussing objects floating and sinking in water (the excerpts were translated from Chinese into English by the research team).

**Excerpt 1 (whole-class teaching approach, S represents a student, T represents the teacher)**

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S1:	Hi, everyone, I am going to present my views on the topic	1
	“Why do some things float?” First, I agree that if an object	2
	is small and heavy, it will definitely sink in water. You can	3
	imagine if a rubber eraser and a piece of paper are put into	
	water, what happens?	
S1:	The rubber eraser will sink and the piece of paper will float.	4
	This shows that an object sinks if it is small and heavy, but it	5
	floats if it is big and light. Second, I believe that the volume	6
	of water also affects the buoyancy of the object.	
S1:	For example, if we have enough water, it is easier to let the	7
	object float. Taking iron ships as an example, although they	8
	are heavy and small (compared to the amount of water), they	9
	can still float. But if you put the iron ships into a small pond,	
	they will sink.	
S1:	That’s all of my presentation. Thank you.	10
	..... (the class applauds)	11
T:	Do you have more ideas to share?	12
S1:	Um. . . . No.	13
	(There is silence for a few seconds in the classroom)	14
T:	Any questions from the class?	15
	(No response from classmates, and there is still silence in the	16
	classroom)	
T:	Okay, S1, according to your idea, if the volume of water is	17
	high enough, all objects will float in the water, right? How	18
	about if we put a rubber eraser into the sea? Will it float?	
S1:	Um . . . I think . . . it floats. . . . but . . . no, I think it sinks . . .	19
	ar . . . no . . . I have no idea.	

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**Excerpt 2 (group work approach, S represents a student, T represents the teacher)**

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S3:	I agree that an object sinks if it is small and heavy. A dry cell [a	1
	metal-case battery cell] is a good example. It sinks if you put	2
	it in water.	
S1:	I agree with S3.	3
S2:	I don’t agree with both of you. I think the type of material	4
	also determines whether it sinks or floats in water. For	5
	example, wood always floats in water, even if it is just a cube	6
	of wood which is small and heavy.	
S3:	Really? I don’t think a cube of wood floats in water.	7
S4:	I agree with S3 and S1. However, I also consider that S2’s	8
	idea partially makes sense. While I do believe that an object	9
	usually sinks if it is small and heavy, I am wondering if the	10
	shape also determines its buoyancy. When I played with	10
	polymer clay, although the clay was small and heavy, it	
	floated in water if I made it flat.	11

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S1:	Yes, I think the shape of the material also affects its buoyancy.	12
S3:	Right, I agree. This can explain why a heavy iron ship can float in the sea but a heavy 20-foot shipping container cannot.	13 14
S1:	In concluding our ideas, I think the weight, volume, and shape also determine the buoyancy of an object. Do you agree?	15 16
S4:	Yes, I agree (S3 is also nodding his head)	17
S4:	S2, do you agree with us?	18
S2:	Yes, I agree. I think our idea makes more sense now.	19

**Comments:** Excerpt 1 shows the presentation of a student in the control class. Although the student successfully supports his opinion (i.e., an object sinks if it is small and heavy [Lines 4–5]) with everyday examples (i.e., a rubber eraser and paper), he mistakenly concludes that the amount of water affects an object’s buoyancy. Regarding the classroom atmosphere, most students remain silent after the presentation and no questions are raised by the classmates. In contrast, it is observed in Excerpt 2 that all group members are actively engaged in the discussion and that together they reach agreement that an object’s shape affects its buoyancy (Lines 8–12). Indeed, the dynamic aspect of the students’ joint construction of conceptual knowledge is a key observation in the experimental class, in which students’ sharing of their preliminary ideas (i.e., wood floats in water) inspire their peers’ further contributions and a developing understanding of the science concept (i.e., the weight,<sup>3</sup> volume and shape also affect an object’s buoyancy [Lines 15–16]).

### **Excerpt 3 (whole-class teaching approach): theme: ‘living and non-living things’**

S1:	I think living things must be able to eat and move. If the things can neither eat or move, we cannot classify them as ‘living things’.	1 2
	For example, a robot can only move but cannot eat, so it is a non-living thing. Another example is a flower. Since it can only absorb sunlight and water (i.e., eat) but cannot move, it is a kind of non-living thing.	3 4 5
	Therefore, I think ‘animals’ are living things because they can move and eat but ‘plants’ are not.	6 7
T:	Okay, S1, thanks for your sharing. Any questions from the class?	8
S2:	Teacher, I don’t agree with S1. I know from TV programmes that sperm are living things. However, they can only move but cannot eat. So, are sperm living or non-living things?	9 10 11
T:	It is really a good question. S1, what do you think?	12
S1:	Um . . . I have no idea.	13

### Excerpt 4 (group work approach): theme: 'living and non-living things'

S3:	I think living things should be able to move, eat and breathe.	1
	We are living things, right? We can do all these things.	2
S1:	Yes, I think all animals are living things. But how about 'plants'?	3
S2:	I don't think plants are living things. They cannot move (S4 was daydreaming).	4
S1:	I think they can. They can grow towards the areas with higher intensity of sunlight but the growth (movement) is very slow (S4 was playing with a pencil on his desk).	5 6
S2:	I think that is impossible (replied vigorously) . . . (There was silence for around ten seconds).	7 8
T:	Okay, we can agree or disagree with each other. However, we should provide reasons to justify our opinions. Any more opinions?	9 10
T:	S4, how about you? Do you remember the ground rules agreed in your group (i.e., active participation in group activities)? What do you think?	11 12
S4:	Um . . . I agree with S3 that human beings are living things. But I don't think plants are living things because they cannot breathe.	13 14
S3:	No, plants can breathe. We call this process 'respiration'.	15
S1:	Oh . . . yes.	16
T:	What do you think, S2?	17
S2:	I think plants cannot move but can grow. Human beings can grow too. So, I think 'growth' is important for living things.	18 19
T:	Great! It is a very good idea.	20

**Comments:** In Excerpt 3, the student from the control class presents his understanding of living and non-living things. Drawing on the examples of a robot and flower, the student considers that if something is living, it must be able to 'eat' and move'. However, when his classmate raises a challenging question regarding the classification of 'sperm', the student does not show much willingness to respond to or take part in the teacher-led discussions, where conflicts with his personal views are involved (Lines 9–13). In contrast, the experimental group's students represented in Excerpt 4 are more critical in their attempts to gauge the understanding of their peers (e.g., "I don't think plants are living things because they cannot breathe" [Lines 13–14]), which successfully prompts the emergence of further clarification and consolidation of science concepts (e.g., "we call this process 'respiration'" [Line 15]). Moreover, it is also worth noticing that the teacher takes an important role in reminding students of their ground

rules (Lines 11–12) and facilitating dialogic interactions when the debate is in deadlock (Lines 7–10). This encourages students to address the challenges raised by their classmates without fear of embarrassment, and provide constructive feedback to their classmates (Lines 18–20).

### *Focus-group interviews with teachers*

As noted, all of the teachers who joined the research participated in the interviews, which explored their views of the effects of group work and traditional whole-class teaching on students' science learning. Due to space limitations, this chapter reports only the results of the questions related to the effectiveness of the pedagogical approaches (i.e., group work vs. whole-class teaching) and the influence of the classroom environment on students' learning performance.

### *Classroom atmosphere and learning progress*

In general, the teachers in the experimental groups (i.e., group work classes) reported better participation and cooperation during lessons than their control counterparts, which in turn contributed to improved science learning on the part of their students. They described the atmosphere in their classrooms as interactive and supportive, with students motivated to engage in the group activities. The teachers in the traditional classes, in contrast, noted little interaction among students, with most remaining silent and only a small number participating in the lesson activities.

- I noticed that the majority of students made improvements and progress in their science achievement as well as their *interaction and participation in the class*. I was delighted that the development was in a forward direction. (T2, *group work*)
- The class atmosphere was very *interactive, fun and supportive*. I had confidence that group work created an interactive and supportive environment, which would definitely be helpful for the students' learning in science. (T2, *group work*)
- I reckon that group work *enhanced the students' cooperation and readiness in learning*. The students have become more *interdependent and have a higher incentive to learn science*. (T4, *group work*)
- I felt very normal. *I found hardly any impact of traditional teaching on the students' understanding*. I perceived that higher achievers were still smart and low achievers still had problems in learning. (T1, *traditional class*)
- I felt comfortable in teaching my class and the atmosphere was acceptable. Nevertheless, I have to confess that there were just *a few chances for students to discuss during lessons*, and I had little interaction with them. (T1, *traditional class*)
- *My class was quite silent as there were always a limited number of students who could participate in the class activities* in the traditional class setting. (T3, *traditional class*)

### *Students' relationships and attitudes*

Most teachers in the group work classes observed that their students became more open-minded in learning during the course of the intervention, with the brighter students becoming less selfish and more helpful and willing to cooperate with others, and the lower achieving students becoming more confident about expressing their opinions. The teachers in the traditional classes, in contrast, observed little change in their students' attitudes and relationships.

- Hong Kong students usually have a hierarchical mindset, which might be attributable to our traditional Chinese culture. *They became more open-minded after working in groups.* In effect, 'teacher' and 'student' were the only two roles in traditional Chinese education and there was a big polarity between them. The high-achieving students regarded themselves as teachers and refrained from learning from the low achievers. They barely had interaction at all. But the use of group work has successfully reconciled the gap between these two groups of students in my class. *All students, no matter whether they are smart or not, cooperated with each other to learn.* (T2, group work)
- I think my class was immersed in an atmosphere of cooperation and competition, which were always interchangeable. *Students were motivated to engage in the group work activities.* (T4, group work)
- *Group work fosters the relationship between different levels of students.* With respect to personality, the smart students became less selfish. The intermediate students became more helpful and the low-achieving students became more confident in learning. (T4, group work)
- *I couldn't observe any substantial changes* in the students' attitudes or personalities. (T1, traditional class)
- The students were quite normal. *I did not spot any of these changes.* (T3, traditional class)

### *Focus-group interviews with students*

As mentioned earlier, around one-sixth (N = 18) of the student participants – nine students from the traditional classes and another nine students from the group work classes – were chosen for the interviews. They provided rich and valuable information regarding the implementation of group work and whole-class teaching in their classrooms.

### *The effects of collaborative and competitive cultures*

From the students' perspective, the majority of the students who were interviewed agreed that group work increased both the *collaborative* and *competitive* atmosphere within their classrooms. Specifically, the teachers provided 'group-based' rewards, which encouraged the students to work hard within their groups

and to interact and help fellow group members to achieve ‘joint’ success (i.e., collaboration). At the same time, a competitive culture was established between the groups because all the groups wanted to contribute their efforts to the whole class and to impress their teachers (i.e., competition). Examples of their responses are given next.

- *The atmosphere of competition and collaboration was enhanced in a group work setting.* As extra marks would be given to the groups who completed the tasks quickly by the teacher, students had more incentives. As a result, every group and every student would compete for the marks in order to prove his or her worthiness. (S7, *group work*)
- As a group, all of my *group mates worked hard and helped each other, or pushed others to complete the tasks* so as to put our group name on the bulletin board to gain additional points. Personally, this created a strong sense of competition between the groups. It also imposed a lot of pressure on the low achievers who always needed to seek help. Perhaps owing to traditional Chinese culture, male students sometimes felt reluctant and embarrassed to ask for help. (S11, *group work*)

However, in the case of the conventional class students, while half of them agreed that the traditional teaching approach *only* increased the competitive atmosphere, some students believed that it increased neither the competitive nor the collaborative atmosphere in their classrooms. Many students expressed that they were under enormous pressure when they worked alone in a competitive and isolated classroom, especially when they were asked by their teachers to explain their ideas (of the science concepts) in front of the whole class.

- *I was under tremendous pressure* when I was asked to demonstrate problem solving. I think all of the students were in a competitive mood. (S6, *traditional class*)
- There were only a few chances where the majority of students could participate in the class activities. Take my class as an example. There were only a limited number of students always engaged in tackling the science problems when the teacher asked them to present their answers on the blackboard, while *most students sat on their chairs with no interaction*, but looked around and gossiped with their classmates. In this circumstance, low-achieving students did not have the chance to participate in the competitive activities. (S2, *traditional class*)

#### *Effectiveness of the teaching methods*

The majority of group work students expressed the view that the collaborative learning method was effective in terms of affording them opportunities for the

knowledge exchange they viewed as crucial to science learning, whereas the traditional class students indicated that any learning progress made was achieved by themselves alone.

- The most substantial benefit of group work was that *it provided the chance to have knowledge exchange with my classmates*. It was particularly crucial in learning science, as we had to discuss and challenge the ideas of other classmates. Certainly, *we also cooperated with each other to solve the science problems and helped each other*. Therefore, I firmly believe that my teaching method improved. (S8, *group work*)
- Honestly, I have a conviction that ‘practice makes perfect’. I put all my efforts into learning and understanding the topics the teacher taught, and I was always eager to raise questions after class. As a result, I found the lesson easy, and *I always made progress by myself*. (S2, *traditional class*)
- *The teaching method was not the primary determinant of my improvement* as learning is our responsibility. We can’t blame the teachers. In fact, employment of whichever teaching method in class is at the teacher’s professional discretion. (S3, *traditional class*)

## Discussion, implications, and conclusion

With regards to the first research question (i.e., what is the effectiveness of group work in enhancing students’ science understanding in Hong Kong primary schools?), in agreement with many previous studies including Galton, Hargreaves, and Pell (2009); Johnson and Johnson (1999); and O’Donnell and King (1999), the study reported in this chapter showed that there was more evidence of both academic and attitudinal gains (in science learning) among the group work students than among the conventional class students. In this respect, the data suggested fairly consistent results between the students’ and teachers’ responses in the interviews as well as the excerpts of the class presentation and group discussion. In particular, all the teachers of the experimental groups strongly supported the positive effects of incorporating the group work in their classes. They commented that group work positively influenced the students’ performance not only in cognitive areas but also in affective domains. However, the teachers in the traditional class expressed reservations about the effects of whole-class instruction on students’ learning in science. In fact, the teachers’ descriptions of their class atmosphere in the interviews were consistent with this. While the teachers in the experimental groups noted that the atmosphere in their classes was accompanied by dialogue, fun, and collaboration, which positively contributed to the students’ understanding of science concepts, the control group teachers observed that the interaction in their classes was at a low level, with only a limited number of students having the chance to actively participate in the class discussions.

Concerning the second research question investigating the influence of group work on Hong Kong students’ learning style in primary classrooms, the teachers



of the group work classes observed that the students became more interdependent, helpful, confident and less selfish. They established better, more harmonious learning relationships between themselves. Furthermore, instead of waiting for the teachers to give model answers, the group work students became more dependent on themselves and their classmates to develop solutions to questions through collective thinking and co-construction of conceptual understanding in science. In contrast, students in the traditional class remained passive and unwilling to express their ideas in the classroom. While a limited number of students were asked to write on the blackboard and share their science understanding, most of the other students sat on their chairs with no interaction, looking around and whispering with their classmates. In addition, the students in the traditional classes reported in the focus-group interviews that classroom participation was restricted to a few high-ability students who dominated the lesson activities.

Although this was a very small-scale, interpretivist intervention study, there are some significant implications. In particular, as noted earlier, research has shown that despite the growing use of collaborative learning in US classrooms, many teachers seem confused about their role in tracking peer group interactions (Clark & Peterson, 1984; Cohen, Lotan, & Holthuis, 2013). One concern is that teachers must also have a conceptual grasp of the theories underlying their roles in facilitating group work activity, so that they can provide guidance in a thoughtful and effective way. Since previous studies (e.g., Chan & Galton, 1999; Zajac & Hartup, 1997) have suggested that training for teachers is the first key element underpinning group work's effectiveness, the teachers who participated in the teaching intervention were trained to facilitate the students' dialogic interactions by providing appropriate prompts when the debate reached a deadlock. Future studies may look into teachers' comprehensive understanding of their roles during group work activities and how this may impact the outcomes of the intervention.

## Notes

- 1 General studies became one of the four core subjects taught in Hong Kong primary schools in 1996. It consists of six modules, including 'Science and Technology in Everyday Life', the aims of which are to spark students' interest in science and to develop their knowledge and skills in technology (Curriculum Development Council, 2011).
- 2 Due to space limitations, only the parts related to the science content of the teaching programme in the larger scale research project (Fung, 2014a) are reported in this chapter.
- 3 'Weight' is a common term used by Hong Kong primary school students when referring to the idea of 'mass' in science.

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# Appendix

Why Do Some Things Float?

What do we mean by 'floating' and 'sinking'?

Observe and then describe the nature (e.g., materials, shape, and size) of the following objects.



*Figure 8.1*



*Figure 8.2*



*Figure 8.3*



*Figure 8.4*

Could you predict which of the above object(s) float on water?

Does an object sink when it is small and heavy?

What determines whether something will float or sink?

Living and Non-Living Things

Can you tell if something is Living or Non-living?

What do you see, hear, smell, or feel as you observe this animal?

What does an animal need to survive?

What determines whether something is living or non-living?

What are living things?





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# 9 Elementary science learning experiences in Singapore

## Learning in a group

*Joanna Oon Jee Ong, Aik-Ling Tan, and  
Frederick Toralballa Talaue*

### Introduction

Science teaching and learning is important for national and regional economic growth, particularly in this technological age. As such, the role of science education in contributing to the growth of modern economies is crucial. What students experience in science classrooms has an impact on what they perceive science to be and how they adopt the practices of science in their everyday lives. Therefore, in this chapter, we argue that unless students' lived experiences of science learning within the science classroom are understood, our efforts at improving science classrooms and learning experiences remain highly theoretical. We maintain that students' voices should be heard – and taken seriously – when teachers plan their lessons. While teachers can certainly obtain feedback about students' learning instantaneously through interactions in the classroom, in this study, we used co-generative dialogues as a platform for students to voice their ideas, questions, and doubts about their science learning experiences. Through this platform, we hoped to enhance students' agency in science learning and to empower them to make more responsible decisions in their classrooms. Through co-generative dialogues with students, we also hoped that teachers would develop a more acute sense of how their professional pedagogical decisions, made before, during and after lessons, can shape students' learning experiences in science.

Despite the benefits of having students' voices heard, not much research pertaining to students' ideas, involvement, and participation has been done, at least in Singapore. Rather, science classrooms in Singapore are characterised as teacher-centred, and instruction is transmissive in nature (Tan & Hong, 2014). The teacher is the authoritative source of knowledge and determines the scope, pace, and format of lessons. This leads to questions such as how teachers tailor their teaching to support learners with diverse needs and backgrounds, and where teachers get their cues to improve teaching and learning in the classroom. Further, do students understand why they are learning what they are learning? How can students' agency (power to act) in the science classroom be enabled so that there is more active participation and discussions?

Mindful of the tensions that could exist between the current, strongly teacher-dominated classroom culture and the more desirous student-directed form of

learning, we decided to use co-generative dialogue as a means to (1) create a space where both teachers and students can discuss their science classroom experiences in a non-threatening and non-judgmental manner, (2) enable students to practice voicing their opinions and views, and (3) increase teachers' comfort levels with sharing their 'authority' with students with regard to issues pertaining to science teaching and learning. As such, these dialogues have the potential to be a powerful tool for teachers and students to engage one another in conversations aimed at creating agentic and progressive science classrooms. Based on the ideas discussed, the research question we sought to answer is "*What do co-generative dialogues reveal about students' ideas of school science and science learning?*"

## **Literature review**

Science teaching and learning is affected by complex interacting factors involving school, family, and wider society. The complexities of these interactions often mean that attempts to understand science learning are challenging since equitable consideration of all parties involved in the activity is difficult. As a result, students' voices are often muted when compared with those of policymakers, teachers, curriculum writers, and parents. There is hence a need to focus on understanding learners' perspectives of science learning. In this particular chapter, we examine primary school students' ideas about science as they surfaced within the context of co-generative dialogues.

### *Science teaching and learning*

Magnusson, Palincsar, and Templin (2004) argued that teaching and learning science as inquiry is a cultural phenomenon and a community-based endeavor, and that learning science in classrooms should reflect the culture of the workbench community and the professional science community. In the professional environment, scientists tend to work in groups and bring together multiple perspectives, and innovative and creative thinking is fostered to create the space for discovery. Among the professional community, ideals such as the importance of argumentation and the coherence of ideas guide how scientific results are interpreted and represented.

Recent research on science teaching and learning has given some attention to 'student voices' by focusing directly on what students think about the form, content, and purpose of their school science education, and exploring the curriculum and pedagogical implications of students' views (Jenkins, 2006). Listening and responding to student feedback not only decreases the alienation that some students feel at school but also provides insights more relevant to students' needs and interests, enhancing student motivation and increasing achievement in science (Flutter & Rudduck, 2004). Furthermore, identifying and responding to student voices models the process of democracy and hence prepares students to participate in collective decision making as citizens of society.

Many studies related to learning science by children have used Likert scale questionnaires, open questions or interviews, and subject preference and semantic differential scales (Kerr & Murphy, 2012). From a social psychological perspective, Potter and Wetherall (1987) argued that questionnaires merely reveal the ‘tip of the iceberg’ and fail to expose any underlying complexity of feelings or views. Besides interviews, few studies have adopted a multi-pronged approach to understanding pupils’ attitudes towards science. The value of such an approach lies not only in offering rich insights into the nature and quality of students’ views, such as experiences that engage and interest students in school science but also offer insights into the underlying reasons for these views (Osborne & Collins, 2001). It was with the aforementioned considerations in mind that we decided to employ co-generative dialogues to explore primary students’ perspectives and experiences of school science in the Singaporean context.

### *Co-generative dialogues*

Co-generative dialogues offer an effective way to explore students’ personal epistemological perspectives. Such dialogues are different from focus-group interviews in terms of pathways of talk as these dialogues adopt a two-way conversational approach instead of a one-way approach, such as when an interviewer pre-determines the topic and direction of talk during an interview. Unlike focus groups, co-generative dialogues do not take place only once but are conducted multiple times with the same students so that rapport and understanding can be established among the participants. Teachers are also included so that they can hear multiple views. This may be a little awkward for both teachers and students at first, listening to others’ feedback about lessons that have been experienced. The students may be reluctant to share in the presence of the teacher, but for the intended purposes of co-generative dialogue, it is necessary to transition from a situation in which students have little voice to one where they do have a voice, while allowing the teacher to still be able to assume his or her institutional responsibility to maintain order in the classrooms (Stith & Roth, 2008). This can be done with the facilitator or researcher reminding participants of the rules and expectations associated with co-generative dialogues, as reflected in the heuristics for co-generative dialogues (see Appendix). Teachers could use this opportunity to engage students in sharing their views of what happened in the classroom, articulate problems in terms of contradictions (e.g., intended versus perceived purpose of an activity), and explore ideas to implement positive changes in classroom teaching and learning practices (Martin, 2006; Roth, Tobin, & Zimmermann, 2002). As such, co-generative dialogues enabled us to design more meaningful and relevant classroom interventions that could potentially improve the teachers’ practices, the relationship between students and teachers, and student engagement and learning.

## **Methods**

In this research, learning is seen from a sociocultural perspective, that is, learning occurs when individuals interact with one another in a community and with

the materials that are present. The realities of the social world are collectively formed by the members in the community, and the artifacts from these interactions (ideas, knowledge, and physical artifacts) are products (Vygotsky, 1986). This sociocultural perspective shaped our decisions regarding the means of data collection as well as the analytic methods.

### *Research design*

This study set out to investigate what co-generative dialogues reveal about students' ideas of school science and science learning, and how these views can be used to improve teaching and learning in classrooms. A large number of studies using co-generative dialogues have been used to support teacher professional development, improve classroom participation among minority students, and explore the culture of learning in the classroom in the Western context, with the participation of mostly secondary school students and teachers (e.g., Martin & Scantlebury, 2009). Therefore, the originality of this study lies in its intention to use co-generative dialogues as a platform to explore primary school students' views about science and science learning in the Singaporean context.

We conducted co-generative dialogues in three primary schools with a total of seven teachers and 35 primary 4 (Grade 4) students. The three schools were a mix of high-performance and mid-performance schools in the national Primary School Leaving Examination (PSLE), a national examination to place Primary 6 students in secondary school. Two of these schools were located in a more affluent neighbourhood, while the third was in a middle-class neighbourhood. These schools volunteered to participate in the study after an invitation was sent to the principal. Primary 4 students were chosen because we assume that after learning science for one year, they are more familiar with the demands of the discipline and are more able to articulate their views on how to improve their own learning. In Singapore, science is taught from primary 3 (Grade 3) (CPDD, 2007).

### *Data collection*

Co-generative dialogues were conducted once every one to two weeks for a duration of half an hour after school. We used the small-group approach (consisting of not more than seven people – i.e., five students and the teacher and researcher) to provide a more intimate setting for the teacher and students to express their views. The students were selected by their teacher, and each group consisted of students with different abilities, gender, and race so that different voices were represented. As part of the co-generative dialogues, students watched video segments of previous lessons and, together with the teacher and researcher, discussed their experiences and how their science learning experiences could be further enhanced. In two primary schools, co-generative dialogues were conducted after the conclusion of a unit on heat and in the third school; it was conducted concurrently with a unit on light. This difference in timing was based on the teachers' preferences, comfort levels, and availability.

Before each co-generative dialogue session, we selected short video segments of less than ten minutes from the previous lesson to show the students. These video segments served as a trigger for discussion. Other artifacts such as workbooks and test papers were also used to stimulate conversations about students' experiences. Typically, after watching the video segments, we posed guiding questions to help the students recall the activity, the difficulties they faced, and any suggestions that they had for improvement. These questions tended to focus on the classroom activities, such as how doing experiments differs from sitting down and listening to the teacher, how they would like their teachers to go through corrections, how they revise before a test, what their difficulties were in using new science terminology, etc.

### *Data analysis*

Audio-recordings from 23 co-generative dialogue sessions were transcribed. Using NVivo software, we used open and axial coding to analyze the data (Creswell, 2012). During open coding, each transcript was first analysed in sentences or groups of sentences relating to the questions asked in each session. For example, when students were asked about the importance of predictions in science, their responses were coded under the category of "Predictions". Once this was completed, responses were further analysed using open coding, looking for repeating patterns, distinct differences, and interesting excerpts. For instance, our analysis of the students' ideas under the "predictions" category revealed two main elements: making predictions during lessons were viewed as (a) redundant and/or (b) restrictive. Open coding done for categories on "fair test" and "science terms" also revealed several elements. The elements from all these categories were then further coded using preliminary axial coding into "Ideas about science process skills". In the case of the category of "accuracy", we did not ask specific questions relating to accuracy, but these ideas emerged as students talked about their experiences with science experiments. These ideas were first coded under the category "accuracy" and then the same process was employed as for the previously mentioned categories.

### **Findings**

Two issues surfaced from our analysis: one relates to students' interpersonal relations and the other to their notions of receiving equal opportunities during group work.

### *Issues related to working in a group*

A study conducted by Jocz, Zhai, and Tan (2014) among primary school students in Singapore, found that group work can spark interest in school science, especially when students perceive that they are engaged in a lot of peer discussion through sharing of information and ideas, working well in their groups, and being able to express their ideas and opinions, including receiving feedback during science class. Social interactions have also been shown to be an important factor in

both triggered and maintained situational interest (Logan & Skamp, 2013) so including group work during science lessons may help to increase learning. Being primary school students, most classes that we observed included frequent group work during either experiments or discussions. Therefore, we were interested in the students' views on their experiences of learning in groups.

### *Interpersonal relations*

We found that students' learning was deeply embedded in the social interactions they described from their recollections of classroom events. We noticed that when students talked about their experiences working with their peers in class, they did not instantly remember an activity, its intended aims, science content, learning outcomes, or even successful completion of the activity, but rather the interpersonal interactions, both positive and negative, that they had with their peers. Excerpt 1 illustrates what students remembered about their group work experiences.

At the beginning of Excerpt 1, we showed students a short video segment of the science activity conducted in groups. The aim was for the students to observe the melting of ice and then answer questions in the workbook. For example, the students are supposed to know what happens when matter gains or loses heat and the three states of matter; thus, some common questions are to describe the change in state and whether heat is gained or lost when the ice melts. Instead of focusing on what they had observed and learnt about the melting of ice, the students candidly and honestly recalled their experiences of "quarrelling" and other, as many teachers would call it, "off-task behaviors", such as wanting to lick the ice cubes.

### **Excerpt 1: Arguing about the explanation (All names are pseudonyms; transcripts were produced verbatim from students' utterances in English)**

<i>Speaker</i>	<i>Utterance</i>	<i>Interpretation</i>
Facilitator:	Ok. First thing, what other things did you remember about this activity?	
Laura:	We saw the ice melt.	Laura highlights that she, presumably along with her group mates, saw the melting of ice first hand.
Siva:	I remember that me and Fatima had a quarrel as to which answer. What was the answer?	Siva points to a shared experience with Fatima and seeks confirmation of the latter's remembrance of the "quarrel".
Fatima:	[inaudible] fighting!	Fatima confirms the shared experience.
Laura:	And you kept on wanting to eat it [gesturing to Isaac].	Laura teases Isaac that he was playing around with the ice. Isaac must have attempted to crack it in his mouth.

<i>Speaker</i>	<i>Utterance</i>	<i>Interpretation</i>
Isaac:	Ice, like spreading itself to water.	Isaac gives a layman's description of the process of melting ice. (It actually sounds poetic!) He captures the change in form from solid to liquid as "spreading itself to water".
Laura:	[to Isaac] Are you trying to lick it?	Laura continues to tease Isaac. This time she refers to "licking" the ice cubes, perhaps in a similar fashion as one would lick cold ice cream on a cone.
Charis:	Um, I remember the ice was like melting and then someone is like touching it.	Charis echoes Laura's answer at the beginning of the discussion. She adds that after the ice melted, "someone is like touching it" to imply that a fellow group mate was perhaps curious as well as playful to confirm that the form had indeed changed
Fatima:	And I remember Brian kept, kept saying like "You know what, I am really thirsty, let's just drink it."	Fatima references Brian's idea, cast in everyday language, that once ice has melted, it can quench one's thirst.

What the students expressed may be perceived as off-task behaviour since their replies did not focus on the intended learning outcome of the lesson. However, closer examination of Excerpt 1 does show most students articulating an idea about ice that they remembered. In contrast, Laura's side comments reveal the informality and candidness of talk among peers, not talk that is careful or too conscious of adults (the teacher and facilitator) who might correct or reprimand her for inappropriate remarks. She embedded her learnings in, what were to her, 'memorable' stories of her group mate's playfulness. She shared that Isaac kept on wanting to 'eat' or 'lick' the ice cubes. Laura's stories reference Isaac's everyday knowledge of ice. While this may not be the intended learning outcome, it seemed to have impacted Laura's recollection of the activity. Since the students seem to remember the interpersonal interactions more vividly than the learning goals of the lesson, teachers could support students' learning by prioritising activities that promote and link positive experiences of interpersonal interaction to science learning.

### *Equal opportunities*

In Excerpt 2, we see students discussing the need for each student to be given a chance to work on the experiments within their groups. While complaints about group work are familiar, such as lack of opportunities to conduct the experiment, disagreement between group members, and difficult group mates disrupting the task, what Excerpt 2 shows is that such issues can potentially distract them from engagement in more productive and meaningful conversations around science.



**Excerpt 2: Disagreements about roles within a group**

<i>Speaker</i>	<i>Utterance</i>	<i>Interpretation</i>
Rick:	I like to do the experiments when I get the chance to do something. But I don't like it when, when my group mates err quarrel over who's gonna do what.	Rick reports experiences of quarrels within the group about task assignments.
Roland:	The experiments are fun but the only problem is everyone is like, "Let me do it, it's my turn." So it's like everybody is quarreling, quarreling over the equipment [inaudible].	Roland re-voices Rick's utterance. He adds that group members fight over opportunities to have a go at working with the apparatus.
Bhav: Rick:	Who gets to do the- They quarrel about, they quarrel about uh who gets to use the, who gets to use the apparatus. [later on]	Rick attributes the quarrels to limited opportunities to do more hands-on tasks within a group context.
Roland:	Ok. Sometimes they say, "I will hold the flask and then you will just pour in the water." And then you will do nothing and because. . .	Roland intimates that some tasks are preferred over others, i.e., to " <i>just</i> pour in water" is assigned a lower status.
Facilitator:	But does this happen all the time?	
Bhav:	Yeah.	
Rick:	Almost all the time.	
Roland:	Almost all the time.	
Students:	It's bad.	
Roland:	Very bad.	
Facilitator:	Why bad?	
Bhav:	Because they give us the worst job. Like they do the very good job. Then they give us [inaudible]	Bhav claims that there are different roles within a group and that these roles are accorded different levels of preferences or prestige.
Roland:	They give us the low standard (low class task) and they get the high class one.	Roland affirms Bhav's idea that different roles have different status.

In Excerpt 2, one of the issues highlighted during this conversation concerned the roles of each group member. Role designation was voiced by students as an important part in the group dynamics that could negatively impact their participation in the learning activity. The students in the co-generative groups collaboratively narrated a "dispute story" (Goodwin, 1990) that resonates reflections on their peers' characters and how they negotiated social relationships with groupmates. They were complaining about the quarrels they faced during group experiments – something they do not enjoy and find annoying. Rick shared that the reason for these quarrels was the unfavourable designation of roles regarding

handling the apparatus during the experiment. In this instance, when the students were given the autonomy to assign roles, some of them felt left out and some perceived themselves to be given more trivial roles by their group mates. The students felt that some roles had a higher status and importance than others as can be seen in their contrastive constructions of certain tasks as ‘good’ and ‘high class’ on one hand and ‘worst’ or ‘low standard’ on the other hand. The students’ talk in Excerpt 2 constructed not only task categories but also categories of persons, as indexed in Roland’s moral protest of exclusion – “They give us the *low standard* [low class task] and they get the high class one”. From this perspective, the students’ quarrel or dispute could then be seen as an attempt from within the group to re-negotiate its existing social organisation (Kyratzis, 2004) for conducting a collaborative learning activity. Confrontations about the social and moral order of the group seems to be another layer of peer group interaction that works alongside (but may interfere with) learning science content through the experiment.

In Excerpt 3, we show that even when the teacher intervenes in an attempt to distribute opportunities so that everyone is involved in the task during group work, some students seem to resist. Prior to group work, the teacher typically asks group members to call out numbers in sequence and then matches a specific task role to the assigned student number. Usually, the teacher will change the role-number assignment so that every member will get to perform various roles across different group activities. As can be seen from the excerpt, a dominant character within a group usually means that others in the group have fewer opportunities for participation.

### Excerpt 3: Dominance within a group

<i>Speaker</i>	<i>Utterance</i>	<i>Interpretation</i>
Facilitator:	In your group, right, Ms Rose has given you some of the roles one, two, three, four. Do you like being given roles?	The facilitator refers to a teacher intervention to ensure everyone has a role to play during group work.
Celestine:	What is roles? [other participants laugh]	Celestine seems to feign ignorance to inject humour into the otherwise serious discussion.
Karl:	[skip some turns of talk] Because every time Cathlyn goes blah blah. . . [skip some turns of talk]	Karl narrates about a fellow group member who dominates the work within a group, disregarding the roles assigned by the teacher.
Steve:	Ariel always tells me this “I must be the first”, because she wants to handle the data logger, she doesn’t let anyone be the first. Actually Ms Rose told Cathlyn to be the first but she (Ariel) insists she has to be the first.	Steve tells a story about a groupmate, Ariel, who displayed a misplaced sense of privilege. Her dominance of the group work led to unequal access to working with the apparatus.

Students brought in brief narrations of their experiences with the intervention for rotating roles among group members and highlighted how certain identities worked against the teacher's intentions. Karl, for example, animated the domineering voice of Cathlyn. He mocked her bossy talk by uttering "blah, blah, blah", clearly conveying his annoyance with her high-status manner of speaking. For his part, Steve complains about Ariel's sense of entitlement in handling the data logger by voicing her character: "I must be the first". He then adds that Ariel's stance deliberately opposed the teacher's appointment of Cathlyn as group leader. In their collusive commentary, both Karl and Steve communicate their experience of exclusion as Cathlyn and Ariel jockeyed for group status with their "above others" attitude. Similar to Excerpt 1, the students expressed how the group members took issue with the existing social organisation, foregrounding members' negotiations for peer status (Goodwin, 2002)

## Discussion

The responses from the co-generative dialogue participants shed light on issues faced by teachers and students in learning science during group work. They also point to the need to re-examine some of our current practices. What adults perceive as useful and helpful ways of learning may sometimes be viewed and interpreted differently by children. Thus, group work is more complex than it may at first appear to be. In students' recollections of what they learned during group work, we heard stories that interwove propositional statements about science concepts with accounts of interpersonal interactions. While these anecdotes highlighted 'misbehaviour' or 'disagreement', they also referenced some of the everyday knowledge that students used as a resource for carrying out practical collaborative activities. This suggests that not all playfulness during group work in the classroom should be construed as being 'off task'. Some fun interactions could actually be laden with relevant sense-making of science concepts.

Furthermore, roles in science learning go beyond just being 'constructors' and 'critiquers' of scientific claims (Ford & Forman, 2006). These formal roles, usually assigned by teachers during classroom activities, may be recast within children's typical informal argumentation during play activities. We argue that the interactions among students before they craft a claim or how they start the critiquing process is as important as examining the quality and content of the claims and critiques. How students negotiate and attain these cognitive roles would be an interesting area of research to look into.

The interaction in Excerpt 2 highlighted that what goes on in group work extends beyond just learning of the content through experiments. Students compared themselves with each other with regard to the roles they were allocated, and consequently perceived inequality in the available opportunities. There may be some students who were not given any roles and this may have caused a feeling of isolation and disempowerment, and even identification among peers as lacking in relevant social capital. This conversation also reveals that 'aggrieved' students differentiate and distance themselves from the other students, referring to themselves as 'us' and other students as 'they'. 'They' referred to students who held 'high class' roles, while 'us' referred to those who were allocated 'low standard'

tasks. ‘They’ may even be students who are smarter, more knowledgeable, more vocal, socially attractive, or have strong personalities, dictating how the group work should be carried out regardless of the instructions from teachers. In other words, there appears to be some form of social stratification with perceived unequal assignment of group tasks. Students who were deprived of the more coveted roles that would have accorded them higher status among their peers felt aggrieved. Students were concerned about being given equal status by their peers, regardless of their abilities or whatever other characteristics. It would be valuable to investigate further whether the roles that students assume during group work might inadvertently encourage social comparison, leading to disagreements and division.

Students’ engagement with school science is not only limited to cognitive tasks; they also attend to their relationships with classmates and teachers. Students concern themselves with the maintenance of socially prized identities that can constrain cooperation and collaboration during group work. Processes of social identification and learning are interwoven in the classroom (Wortham, 2006). Attempting to identify the boundaries between official educational activities (i.e., those aspects concerned with the intended learning outcomes of the curriculum) and interactions within a group is difficult (Swann, 2007). Despite the claimed benefits of learning through group work, closer analysis of the small sample participating in this study highlights the need to consider social and relational factors, or the group work may actually make science learning more difficult and less engaging, particularly for students who feel less empowered – and even disempowered – by the group dynamic. Instead of promoting inclusiveness, group work may be a source of isolation and even oppression for some. Teachers may need to be aware not just of the isolation among group members, but the reasons behind this isolation.

### *Implications for teaching and learning*

These co-generative dialogues gave the students a platform on which to candidly share with each other and their teachers their experiences of being learners of science in their respective classrooms. The co-generative dialogues also provided opportunities for teachers to listen in to students’ views, which could be a starting point for building rapport and reflecting on their practice.

Since most students referenced their interpersonal relations as they performed an educational activity and made sense of science concepts, it is important to create positive social experiences connected to the learning outcomes. This is not to say that group work should always be conducted in a fun and enjoyable manner, but certain rules should govern the experiences in group work such that all students can be involved and their contributions are valued. For example, Mercer, Dawes, Wegerif, and Sams (2004) advocate for practice in which students abide by some ground rules to ensure that exploratory talk in a cooperative activity becomes democratic and reasoned, emphasising inclusive participation and direct solicitation of others’ views to arrive at a consensus. Such a language-based practice has been found to significantly improve students’ reasoning, learning, and language and communication skills (Littleton & Mercer, 2010).

In the experiences reported earlier, there seems to be a neglect of the social dynamics that shaped the trajectory and outcome of the group work activities. In this study, we found that students attached certain identities to the roles they were allocated. Permanent assignment to an ‘inferior’ role creates resentment that may eventually grow into divisiveness and distancing within the group. Students seem to be saying that they want to be valued, not just for their presence but for what they say and what they do in class. Swann (2007), in her critique of Mercer et al.’s (2004) research, argued that it is not possible to neutralise or suspend the social conditions of talk by merely introducing participatory ways of speaking. Rather, she suggested that teachers and researchers become more sensitive to and accommodating of the communicative strategies students employ and the full range of their interactional effects in group work.

Looking back at our research question, the co-generative dialogues helped us better understand students’ views and perspectives on school science and how they prefer to learn science. The students’ candid replies reflected honesty and trust that they could be themselves and give unscripted answers without being judged or penalised in class by their teacher. Most of the teachers took part in the co-generative dialogues by voluntarily asking questions with the intention of eliciting student feedback in order to improve their practice. Thus, the multiple sessions of co-generative dialogue helped to build a certain level of rapport and trust between the teachers and students.

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# Appendix

## Heuristic for productive co-generative dialogue sessions (Roth, Tobin, & Zimmermann, 2002)

- 1 Respect (between participants)
- 2 Rapport (between participants)
- 3 Inclusion of stakeholders (student teachers, teachers, students, school personnel, researchers, etc.)
- 4 Ways to participate:
  - 1 Coordinating discussion
  - 2 Listening attentively
  - 3 Initiating dialogue/ideas
  - 4 Posing critical questions
  - 5 Providing evidence
  - 6 Expressing an opinion (agree/disagree)
  - 7 Speaking freely
  - 8 Clarifying and elaborating on ideas
  - 9 Suggesting alternatives for actions
  - 10 Evaluating ideas and practices
- 5 Opportunities to participate:
  - 1 Contributing to an equitable playing field
  - 2 Listening attentively
  - 3 Making space to participate
  - 4 Showing willingness to participate
  - 5 Making invitations to participate
  - 6 Refusing all forms of oppression

# 10 Focusing on scientific literacy

## The value of professional learning

*John Loughran*

### Introduction

The academic debate about scientific literacy typically draws on arguments that have existed for a considerable period of time in science education around issues pertaining to curriculum design, meaningful learning, student engagement, and the relevance of science learning in school classrooms. However, when the debate is viewed from a school or teacher perspective, scientific literacy, especially in the primary (elementary) classroom, takes on a different, more pragmatic character. This chapter, based on a longitudinal study of a whole-school approach to scientific literacy, illustrates how the notion of scientific literacy can be a valuable way of encouraging teachers to be more focused on their teaching of science and become a catalyst for helping them to move beyond an ‘activities that work’ (Appleton, 2002) approach to the teaching of science.

Central to the outcomes of the study reported in this chapter are a number of important situational conditions that had a major influence on the way scientific literacy was understood, developed, and evaluated by the participating teachers. First, the school, in Melbourne, Australia, had been involved in a professional learning programme (STaL: Science Teaching and Learning project) over five years, in which 13 of the 25 staff had participated. Second, school leadership (principal, deputy principal, curriculum coordinator, and senior teachers) was not only supportive of the professional learning programme, they actively sought staff involvement, initiated in-school professional learning to support and extend STaL ideas within the school, and also helped to ‘kick start’ the multi-domain scientific literacy project at the heart of this chapter. Third, the Catholic Education Office (Melbourne), the education bureaucracy responsible for managing Catholic schools,<sup>1</sup> was also an active supporter of all of the work at the school and helped to fund many aspects of the project – something that the school would not normally have been able to manage within their local budget. Finally, there was a clear acceptance by participants that change is a process not an event, and that educational change, “is not a single entity, even if we keep the analysis at the simplest level of an innovation in the classroom. Innovation is multidimensional . . . change has to occur in practice” (Fullan, 2007, pp. 30–31). Each of these conditions is briefly outlined in the following section in an attempt to contextualise the scientific literacy teaching and learning outcomes described in the rest of the chapter.



## Conditions for change

### *1) The Science Teaching and Learning (STaL) project*

The STaL project (Berry, Loughran, Smith, & Lindsay, 2009; Smith & Lindsay, 2014) was based on the idea that teachers need to be at the centre of their own professional learning, and that encountering challenging (sometimes confusing and confronting) learning situations is an important way of reimagining science learning in order to translate that learning into teaching. STaL was a year-long programme that comprised two 2-day residential workshops, follow-up school visits and support between workshops, and a final (fifth day) writing day designed to create an opportunity for reflection and closure through case writing (Barnett & Tyson, 1999; Lundeberg, 1999; Shulman, 1992). The cases from that writing day were subsequently published as a book (see, for example, Berry & Keast, 2009, 2010; Keast, Lancaster, Loughran, & Panazzon, 2013; Loughran & Berry, 2006) with copies supplied to all participants, their school leadership and the Catholic Education Office (Melbourne). Importantly, involvement in the program required a minimum of two teachers from participating schools in order to situate professional learning as a shared experience that might have lasting impact.

Throughout the STaL programme, the ‘why’ of teaching particular subject matter content in particular ways, hinting at the place of pedagogical content knowledge (see Shulman, 1986) in science, was a touchstone for learning science and for examining the pedagogy underpinning the anticipated learning approach and outcomes. The case writing was designed to support participants to reflect on the ways in which their learning from STaL had been enacted in their classroom practice, and to facilitate a shift in their teacher talk from the ‘what and how’ to the ‘why’ of teaching. In essence, the cases were designed as a vehicle for making participants’ tacit knowledge of practice explicit, both for themselves and for readers of their cases. In the STaL programme, making the tacit explicit was an enduring theme because

if little attention is paid to teacher thinking then much of that practice will remain tacit, elusive and difficult to define. If that is the case then some of the most important knowledge that shapes practice could be dismissed or ignored thus reducing the possibilities for understanding expertise in teaching.

(Loughran, 2010, p. 13)

### *2) Genuine support from the school leadership team*

At the outset, the school leadership team enthusiastically chose to support their teachers:

The leadership team believed that the biggest influence on our students was teachers so we decided to concentrate more time, finance and opportunities on finding ways to support the development of teachers’ practice in our

school context . . . We gave our teachers permission to take risks with their teaching and learning ideas in the classroom and trusted them to make decisions that would be appropriate to their students' learning in their classroom contexts.

(Grace, 2011, p. 21)

When the first STaL program was offered, four teachers attended from the school described in this chapter. On their return to school, the leadership team agreed to their request to have as many teachers as possible be involved in the program each year from then on. That decision meant that the school made a commitment to professional learning in science that would extend over five years.

The first group of staff involved in STaL took the ideas from the programme and began to work with them in innovative ways within the school and even developed their own book of case studies to capture and portray their learning from their 'in-school' project (Smith & Howard, 2007). As a consequence of the enthusiasm of staff to pursue further development in science, the school leadership team initiated an ongoing in-school professional learning project through which science would become an essential element of the curriculum. The programme was based around the involvement of a critical friend (external consultant) who supported staff in making a major change in the curriculum focus, from science as a separate subject in the weekly programme to being embedded in all units more generally. The approach was called the multi-domain approach and both teachers and students found that it dramatically changed their view of STaL and became a major impetus for greater valuing of, and engagement with, science across the school (Smith, Loughran, Berry, & Dimitrakopoulos, 2011).

### ***3) Systemic support through the Catholic Education Office, Melbourne (CEO(M))***

The CEO(M) – the education bureaucracy responsible for Catholic schools in Victoria, Australia – supported the school in developing its multi-domain approach through a grant that enabled employment of the critical friend (an experienced science educator who was the school support team member for the STaL project). The CEO(M) funded the project, recognising that “Allowing real time for deep and sustained change is rare among education bureaucracies because it goes against most bureaucratic system imperatives which insist on overt outcomes in short time periods, frequently in annual allotments” (Lindsay, 2011, p. 12). The CEO(M) supported the programme because it wanted to support teachers to take charge of their own professional learning and so deliberately adopted

a “light-touch” approach from a system point of view and no pressure in terms of timeframes for success . . . instead surrounding the school with good people and funding to support autonomy in decision making, development

directions and expected actions . . . so that the school maintained professional responsibility in driving its own change.

(Lindsay, 2011, p. 12)

The CEO(M) was further encouraged to offer system support because of the school's association with a University (Monash), and did so with the view that a relationship would develop that "focussed on the nature of interactions rather than measurable, short term outcomes" (Lindsay, 2011, p. 13). Finally, the CEO(M) also provided support because of the view that explicit structures for reflection and the use of a critical friend would facilitate teachers developing their own understandings of important approaches to, and the advancement of, science literacy with their students. Such an approach from a systemic perspective is unusual but was driven by the senior science education officer (Simon Lindsay, quoted earlier) who was sensitive to issues around teacher professional knowledge, STaL, and educational change.

#### *4) Change is a process not an event*

A major facet of the school's approach to focusing on scientific literacy was the view of staff that change required a focus that extended beyond individual teachers in their own classrooms. They were firmly of the view that a whole-school approach was essential. Hence, as they developed and formalised their multi-domain approach, there was a commitment to change as a process. Having already spent two years developing their in-school STaL extension project, the school committed to three years for the multi-domain project; over the five years in total, the leadership team's commitment to the necessary resources for pursuing their goals was unswerving. For example, the curriculum coordinator took on a major role of managing the multi-domain project in collaboration with the critical friend, and regular planning, feedback and review meetings (year level, small group, whole staff) became an ongoing structural feature of the school's approach to professional learning.

### **A multi-domain approach to developing scientific literacy**

The multi-domain approach developed at the school was as a direct result of the teachers' increasing desire to ensure that their students' learning of science was connected, meaningful, and relevant, and that it was not seen as something that only happened in the timetabled period known as 'science'. This represented quite a shift from traditional approaches to science teaching in primary schools.

As teachers started to develop personal beliefs about scientific literacy, that is what they valued in their teaching and their vision for meaningful learning, they became increasingly concerned that their existing planning and teaching

practices might actually be contributing to ‘disconnected’ student learning. They were beginning to question whether their students were leaving their thinking and ideas behind as they moved to new units; never really exploring the potential of their ideas and thinking in a unit as they pushed towards a different topic.

(Smith, 2011, p. 30)

The multi-domain approach placed scientific literacy – in terms of the practical implications for both curriculum and learning – at the centre of the enterprise. The multi-domain approach involved the following:

- curriculum planning designed to foster meaningful links across curriculum areas in order to enhance students’ learning across subject areas;
- collegial planning around four unit topics for the year (as opposed to each subject area being distinct and separate), with each topic allocated to a specific school term (each topic – for example, Relationships, Sustainability, Technology, and Safety – was covered simultaneously at all levels within the school at the same time; a school year comprises four 10-week terms);
- purposefully developing learning connections across topics and linking learning in each unit across the year; and
- formal and informal opportunities for professional discussion to examine alternative approaches to planning and teaching in an attempt to provide effective conditions to enhance students’ scientific literacy.

The multi-domain approach meant that topics were, therefore, conceptualised in such a way as to move away from the more traditional unit blocks of subject matter teaching. An essential element of the multi-domain approach was also explicitly creating conditions and organisational structures to support teachers to take charge of their own professional learning. To this end, the project revolved around the input, challenging and ongoing support from a critical friend who was very experienced in working with teachers to develop and enhance their professional knowledge of practice. The critical friend provided specific planning support for teachers across all levels within the school, and aimed to build teachers’ decision-making capacity through the development of professional conversations around key thinking, communication skills, and science concepts that might support students in developing their scientific literacy. In collaboration with the teaching and learning coordinator, the critical friend also supported the classroom teachers through workshops, classroom observation and participation, meetings and planning days, and continually sought to bring teacher learning to the fore through explicit structures for reflection on their practice, how it impacted student learning, and what that meant for the development of understandings of scientific literacy.

The success of the multi-domain planning approach (beyond a reconceptualisation of the nature of curriculum and subject timetabling) was based

on an expectation that participants could openly and honestly share their professional practice, their honest critiques of their own teaching and learning, and how they might work together to make a difference to the ways in which they taught and their students learnt. In essence, the multi-domain approach evolved as a response to the teachers' desire to break down the organisational structure of school learning as discrete units of subject matter content in different domains. Seeing science in the everyday world through the multi-domain topics (noted earlier) was the intention, but it had benefits for all participants (teachers and students) in unanticipated ways as curiosity, engagement, questioning, and research became key aspects of teaching and learning science that infused topics. In so doing, teachers' confidence in moving away from a 'science as facts and information' to 'science as inquiry and discovery' changed notably, and students' understanding of science was positively impacted.

My confidence in teaching science continued to grow . . . for the unit of 'Relationships', my Year 4 class focused on how all living things are dependent on forming relationships for their survival and continued existence. The students were able to investigate the relationships of one of five animals – dolphins, elephants, weedy sea dragons, orangutans and bees. This learning led directly to the second term unit, 'Sustainability' and the study of endangered animals (with strong links to the impact of Palm Oil on orangutan habitat).

(Walsh, 2011a, p. 97)

## **Developing scientific literacy**

When Roberts (2007) described his two differing positions of science curriculum design he rekindled interest in the nature of science literacy. He described Vision I, which has a strong focus on science content knowledge, as scientist-centred. He compared this to Vision II, which is much more student-centred and context-driven. In considering these two positions, Aikenhead (2007) noted that Vision II "seeks to enhance students' capacities to function as lifelong, responsible, savvy participants in their everyday lives; lives increasingly influenced by science and technology" (p. 1) – a view that sits comfortably with hopes for, or expectations of, what it might mean to be scientifically literate in the modern world.

Roberts' two visions also speak to the nature of students' school science learning. Typically, Vision I is bemoaned as that which is most commonly experienced by students, whilst Vision II captures the hopes for how science learning should be experienced. Clearly, a Vision II view of the curriculum is appealing to teachers, but as the literature continues to illustrate, implementing a Vision II approach in practice appears difficult to achieve (or maintain at a whole-school level). The point is that developing scientifically literate citizens through their schooling experiences can easily reside in the realm of rhetoric without being realised in practice.

Despite the fact that Fensham (2008) argued that, “scientific literacy does not have a fixed meaning or definition. Nor is it a single notion” (p. 28), the label itself continues to attract attention because it speaks to an everyday interpretation that appears to have some traction:

Scientific literacy has become an internationally well-recognized educational slogan, buzzword, catchphrase, and contemporary educational goal . . . The term is usually regarded as being synonymous with “public understanding of science”.

(Laugksch, 2000, p. 71)

Through the multi-domain project described earlier, there was tacit acknowledgement of the need for a shift from a Vision I to a Vision II view of the curriculum. In many ways, but without the Vision I/Vision II language, that shift is what was being pursued across three aspects of STaL: the stated curriculum, teachers’ practice, and students’ learning. Each of these is considered next.

### *1) Curriculum*

In relation to the curriculum, the multi-domain approach necessitated a shift in the way that the curriculum was conceptualised and organised. Walsh (2011b), a Grade 6 teacher at the school, described the curriculum shift as an explicit move away from domain-specific organisation of subjects that had been the ‘norm’ for primary school curriculum organisation throughout his teaching career. He noted how the common ‘scope and sequence’ approach that had previously been used to direct which ‘content’ needed to be covered in each specific subject unit (e.g., health, science, mathematics) quietly subsided as the idea of teaching themes began to be translated into more broadly based, term length (10 weeks) topics such as Safety, Communication and Sustainability. As a consequence, the curriculum began to be viewed more holistically because “through the inquiry of these topics [teachers] were able to incorporate teaching and learning of all relevant subject areas” (p. 82) in ways that they previously would not have entertained.

In a similar vein, Kakos (2011) described how, through a focus on scientific literacy, she had come to see the need to move away from a view of teaching science as being about “just preparing a future generation of scientists by focusing on content-based science teaching and learning” (p. 117) to a ‘Science for All’ (Fensham, 1985) approach. Through the multi-domain approach, she felt as though there was a curriculum shift that helped her approach teaching in such a way as to

enable people to understand scientific issues in the media, locally and globally. [Because] the aim of schools [should be] to provide a curriculum which encompasses all students in order to help them become scientifically literate – not just those who have an inclination towards becoming scientists.

(p. 117)

With curriculum structure and organisation acting as a catalyst for change, many of the common issues pertaining to science teaching in primary schools were challenged. These included confidence in teaching science (Skamp, 1991, 1997), the need for activities that work (Appleton, 2002), and the influence of subject matter content on teaching (Parker & Heywood, 2000; Shallcross, Spink, Stephenson, & Warwick, 2002).

## 2) *Teachers' practice*

In terms of teaching for scientific literacy, Adams (2011) described an evolution in her practice that led her to see her role as an educator in a different way. She developed a way of concentrating her reflection on practice through the use of an 'action that matters' mantra that led her to question what she did, how and why. By actively questioning her practice, her teaching behaviour changed, which simultaneously impacted her students' learning. She inquired into her teaching by asking, "What can I do to allow the students more input into their learning? How do I guide possible directions for students' learning whilst still allowing them room to explore? How can I challenge them to develop deeper understanding?" (p. 62). As a consequence of honestly questioning her teaching in this way, she noticed that

my change in behavior allowed me to actually listen to students' dialogue and I realized that their behavior was also changing. They were clarifying and challenging each other . . . my responsibility had shifted from organising the answers and all the work to fit into a neat little box, to supporting the learners in their journeys of discovery . . . in my mind now scientific literacy means that a learner can ask questions and find answers to questions derived from curiosity about the science in their everyday experiences . . . this is action that matters.

(p. 62)

## 3) *Students' learning*

It seems fair to assert that nothing changes teachers' practice as much as observable changes in the quality of their students' learning – it is the link between teaching *and learning* that is so crucial. Through the multi-domain approach to teaching for scientific literacy, the participating teachers consistently noted changes in student learning that encouraged them to persist with teaching science in (what for them) were ways that were new and challenging. They gained professional satisfaction from seeing their students' learning behaviours change.

I have been amazed with how connected my students have become with learning, the world in which they live and the questions they generate as a consequence of this connectedness. . . [they have become] quite empowered that they play a part in sustaining their environment. What blew me away was the feedback from parents about the conversations that their children

were instigating at home and the actions they were asking their families to consider in light of their learning.

(Adams, 2011, p. 63–64)

Howard (2011), one of the original first time STaL participants who instigated and encouraged much of the professional learning within the school over time, described how her teaching had shifted from a need to ‘have all the answers’ to supporting, nurturing and encouraging student learning. That shift in her practice occurred, not least, because she saw qualitatively different learning in her students:

We videotaped a small group of students talking about their learning and I was amazed at the extent to which they were able to use the understandings from [their] experiments, to make evaluations and predictions in other situations. They had recorded data, followed directions, made predictions and verified their thoughts with written answers that were well worded with scientific terminology and they shared these with the school community. They had been able to transfer the learning to community issues that would have real life meaning for them. I had the answers but because these students found the answers for themselves, the learning was more valuable for them.

(p. 56)

## **Conclusion**

The multi-domain project that led to a whole-school approach to teaching for scientific literacy resulted in a book that featured insightful teacher-written chapters of their learning about, and practices of, teaching for enhanced scientific literacy in their primary school (Loughran, Smith, & Berry, 2011). As this chapter illustrates, school level change requires actively creating conditions to support teachers’ professional learning in ways that are not so likely when change is mandated or driven in a top-down manner. The teachers involved in this project demonstrated well how they had fundamentally changed their teaching of science as a consequence of the multi-domain approach, and how their changed practice impacted their students’ learning of science.

The teachers involved in this project also demonstrated how, in developing professionally together, they arrived at a shared language of teaching and learning that helped them to better understand and value their professional knowledge of practice – a shift that could not be imposed by others. Their efforts were exceptionally well regarded by the CEO(M) and also attracted attention from a Swedish science teacher educator who visited the school to see for herself what the project was doing. She concluded,

My experiences of working with primary teachers is generally that they tend to lack self-confidence in teaching science and that, as a consequence, science lessons are often mainly teacher directed. What struck me was that [these] teachers seemed confident in their roles in the classroom and worked



in an inquiry-based manner in which they stepped back and let the students be active participants in all aspects of learning . . . they challenge students to question their world and try to help them see that science is not always about experiments and people in white lab coats . . . I was impressed by the way the teachers highlighted that there had been a shift from their own thinking about where to find science in a unit to now seeing that science is everywhere . . . they had revised their way of thinking about science and scientific literacy . . . they can work with science in the classroom and discover together with the students rather than simply teaching to the students.

(Nilsson, 2011, p. 134–135)

Nilsson's visit to the school and subsequent report of her observations created a form of external validation that was greatly appreciated by the students, parents, teachers, school, and the CEO(M).

In conclusion, there is much we still have to learn about sharing teacher-directed educational change. The multi-domain project described earlier offers a glimpse into one way of progressing that agenda.

## Note

1 The Catholic Education Office (Melbourne) educates 1 in 4 students in Melbourne, has 329 schools (a mix of Primary and Secondary) involving 146,400 students, and 16,700 teaching and non-teaching staff (see [www.ceomelb.catholic.edu.au/our-schools/](http://www.ceomelb.catholic.edu.au/our-schools/) for more details).

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# 11 Analysis of questions in primary school science textbooks in Japan

*Manabu Sumida*

## Introduction

In science classes, the use of scientific questions and language in textbooks often dictates science teaching and learning. For instance, Hosono (1995) reported that more than half of Japanese primary and secondary school science teachers use topics or concepts from their textbooks in the classes they teach. Pizzini, Shepardson, and Abell (1992) revealed that about 80% of questions in middle school science textbooks were ‘Input’ level. Dunne, Mahdi, and O’Reilly (2013) introduced a survey of Irish primary school science, which showed that 72% of the surveyed teachers use science textbooks in their teaching. Schmidt, Raizen, Britton, Bianchi, and Wolfe (1997) and Valverde, Bianchi, Wolfe, Schmidt, and Houang (2002), in a cross-national analysis, identified textbook content as an important mediator between the intended curriculum (system goals) and the implemented curriculum (classroom instruction). The content of science textbooks has therefore come under scrutiny. Overman, Vermunt, Meijer, Bulte, and Brekelmans (2013) found different patterns of textbook questions in context-based and traditional secondary chemistry curricula. Yamaoka, Sumida, Nakayama, and Matsumoto (2015) analysed 508 questions from secondary science textbooks and found patterns in common with questions of the Upper Secondary School Entrance Examinations.

Hirayama, Ono, and Takagi (1996) analysed practice exercises in textbooks used in Japanese high schools and in the first years of college as well as project physics and Physical Science Study Committee physics textbooks from the United States. They found that all physics textbooks in Japan contain questions that require students to select a formula and solve a problem, while the US textbooks set up scenarios and ask for qualitative responses.

The content of school science textbooks are not only scientific and pedagogical but also epistemological (e.g., DiGiuseppe, 2014; Niaz & Maza, 2011). Koulidis and Tsatsaroni (1996) divided topics covered in previous research on the analysis of science textbooks into six categories: (1) approaches to the material, (2) language and ease of reading, (3) student achievement, (4) epistemological perspectives, (5) social perspectives, and (6) review/other. They analysed physics and chemistry textbooks of lower secondary schools in Greece and found

that most of the questions were difficult or metaphorical, and that chemistry textbooks, in particular, contained many metaphorical questions. Niaz and Maza (2011) pointed out that there were very few chemistry textbooks that satisfactorily include content about the nature of science.

Tarman and Kuran (2015) and Upahi and Jimoh (2016) applied Bloom's taxonomy to analyse questions in textbooks. The 'taxonomy' of different types of questions (Bloom, 1956) is very important, while studies related to domain-specific characteristics of questions in science need to be conducted from language-culture perspectives. Dehghani et al. (2013) compared a storybook text by Native American authors and non-Native American authors and noted the influence of 'epistemological orientations' due to the cultural background of the authors. Furthermore, few studies have been conducted on the linguistic nature of questions in science textbooks used in the early grades. Japanese science education officially starts in grade three. The objectives of the Japanese course of study in science for grade three are 1) to develop perspectives and ideas about the properties and functions of weight, wind, force of rubber, light, and magnets and electricity through investigation comparing phenomena involving these matters, and through probing the identified problem and making learning material with interest, and 2) to foster an attitude of loving and protecting living things and to develop perspectives and ideas about the relationship between living things and the environment, the relationship between the sun and its effects on conditions on Earth, through investigation comparing familiar animals and plants, and sunny and shady spots, as well as through probing the identified problems with interest (MEXT, 2008). At this stage, children are expected to respond to scientific questions in their science textbooks. This chapter describes the characteristics of questions contained in Japanese primary school science textbooks, asking: What are the types of questions found in science textbooks used in primary school science classes, when children formally encounter scientific views and thinking for the first time?

## Methodology

The study reported here analysed questions in primary school science textbooks published by Publishing Company T (*Tokyo Shoseki*) that were inspected and authorised by the Ministry of Education in 2004, namely, for each of the grades respectively: New Edition New Science 3, New Edition New Science 4 (volumes I and II), New Edition New Science 5 (volumes I and II), and New Edition New Science 6 (volumes I and II). In Japan, all primary school textbooks are required to follow the Japanese Course of Study and to adhere to Japan's textbook inspection system. This is to ensure the level of quality in primary school textbooks, including for science. These textbooks are used by children attending compulsory education free of charge. Valverde et al. (2002) reported that Japanese textbooks have a small number of pages and the content is selective.

Primary school textbooks contain information presented in a variety of visual formats, including text, illustrations, figures, and tables. The primary data for this study were the texts extracted from the textbooks. Although

quantitative analysis may be useful, qualitative analysis by means of text mining was used. Text mining is a method by which less visible facts and trends may be extracted from a large amount of text data. Text data is a rich resource for analysis, and is available in a range of forms, such as query records from call centres, sales reports, bug reports, and blogs. The analysis in this study was conducted using “Trend Search 2015” by SSRI (Social Survey Research Information Co., Ltd.).

## Results

### *Frequency of questions in the primary school science textbooks*

First, all questions in the textbooks were extracted, and their frequency sorted in terms of grade and content area, as shown in Table 11.1. The content area labelled ‘other’ included questions related to science in general, such as ‘*What kinds of things are studied in science?*’ (New Science 3, p. 0)

Table 11.1 shows that the number of questions did not simply increase as the grade level rose. Although the number of questions did increase dramatically from 130 in the third grade to 241 in the fourth grade, the total number of questions in fifth and sixth grade textbooks was lower than in the fourth grade textbooks. An examination of the content area breakdown also shows that there were far fewer questions related to living things and the environment, than to matter and energy or the Earth and space. A chi-square test using content area (4)  $\times$  grade level (4) produced statistically significant results ( $\chi^2 = 40.14$ ,  $df = 9$ ,  $p < .01$ ). A residual analysis revealed that, in content area A, the frequency of questions in the third and sixth grade textbooks was significantly higher than for the other content areas, whereas it was significantly lower in the fifth grade textbooks. The frequency of questions in content area C, in turn, was significantly higher in the fifth-grade textbooks but significantly lower in the third grade textbook. No significant difference was found across grade levels in the frequency of questions in content area B.

Table 11.1 Number of questions by grade and content area

<i>Content Area</i>	<i>Third Grade</i>	<i>Fourth Grade</i>	<i>Fifth-Grade</i>	<i>Sixth Grade</i>	<i>Total</i>
Content Area A (Living things and the environment)	67	80	63	97	307
Content Area B (Matter and energy)	48	107	101	81	337
Content Area C (The Earth and space)	10	48	62	31	151
Other	5	6	5	7	23
Total	130	241	231	216	818

***Do science classes begin with the question ‘why’?***

Children generally have a seemingly endless supply of *why* questions about natural phenomena, such as “Why is ocean water salty?” The question arises as to how many *why* questions are included in primary school science textbooks. Only 15 *why* questions appeared across the textbooks studied: one in the third grade, six in the fourth grade, four in the fifth grade, and four in the sixth grade textbooks. These questions were translated in collaboration with a native English speaker:

**Third grade**

- *Why do the areas covered in shadow change?* (Content Area C, p. 46)

**Fourth grade**

- *Why have various kinds of wildlife recently appeared in this area?* (Content Area A, Volume I, p. 5)
- *Why is this?* (Content Area B, Volume I, p. 12)
- *Why does the size of the electrical works change depending on how the batteries are connected?* (Content Area B, Volume I, p. 16)
- *Why does the motor spin quickly?* (Content Area B, Volume I, p. 25)
- *Why has more wildlife recently appeared in this area?* (Content Area A, Volume I, p. 29)
- *Why do you think the mist or steam appeared?* (Content Area C, Volume II, p. 37)

**Fifth grade**

- *When the flowers bud, why are they covered with a bag?* (Content Area A, Volume I, p. 45)
- *Why do the sizes and shapes of the rocks in content areas A, B, and C differ?* (Content Area C, Volume I, p. 60)
- *Why is the time for ten swings measured three times?* (Content Area B, Volume II, p. 40)
- *Why is it measured three times?* (Content Area B, Volume II, p. 44)

**Sixth grade**

- *Why do living organisms thrive on Earth?* (Content Area A, Volume I, p. 1)
- *Why is that?* (Content Area A, Volume I, p. 27)
- *Why do cliffs have a striped pattern?* (Content Area C, Volume II, p. 3)
- *Why can geological layers of soil at the bottom of oceans and lakes be seen on land?* (Content Area C, Volume II, p. 12)

*The number of yes/no questions*

The number of yes/no questions (questions that can be answered with a simple 'yes' or 'no' response) in the textbooks were examined and sorted by grade and content area. Table 11.2 shows that 42% of the questions in the third grade textbook were yes/no questions. As grade level increased, this percentage did not decrease. In fact, the lowest percentage of such questions was found in the fifth-grade textbooks – namely 23%. A chi-square test using grade level (4)  $\times$  yes/no type questions (2) produced statistically significant results ( $\chi^2 = 15.383$ ,  $df = 3$ ,  $p < 0.01$ ). Compared with other grade levels, the third grade textbook had a significantly higher ratio of yes/no questions, whereas the fifth-grade textbooks had a significantly lower ratio.

A content area breakdown reveals that content area B had the highest ratio of yes/no questions – namely, 34%. A chi-square test using content area (4)  $\times$  yes/no type questions (2) produced statistically significant results ( $\chi^2 = 12.561$ ,  $df = 3$ ,  $p < 0.01$ ). Compared with other content areas, content area B had a significantly higher ratio of yes/no questions, whereas content area A had a significantly lower ratio.

A chi-square test using content area (4)  $\times$  grade level (4) also produced statistically significant results ( $\chi^2 = 17.615$ ,  $df = 9$ ,  $p < 0.05$ ). The ratio of yes/no questions in content area A in the fourth-grade textbooks was significantly lower than other content/grade combinations, whereas that in content area C was significantly higher. No significant difference was found across grade levels in the frequency of yes/no questions in content area B.

*Table 11.2* Number of yes/no questions by grade and content area

<i>Content Area</i>	<i>Third Grade</i>	<i>Fourth Grade</i>	<i>Fifth Grade</i>	<i>Sixth Grade</i>	<i>Total</i>
Content Area A (Living things and the environment)	22 (67)	10 (80)	19 (63)	22 (97)	73 (307)
Content Area B (Matter and energy)	25 (48)	40 (107)	23 (101)	27 (81)	115 (337)
Content Area C (The Earth and space)	5 (10)	16 (48)	9 (62)	4 (31)	34 (151)
Other	2 (5)	3 (6)	2 (5)	2 (7)	9 (23)
Total	54 (130)	69 (241)	53 (231)	55 (216)	231 (818)

The numbers in parentheses indicate the total number of questions in each grade level/content area.



***Frequency of non-yes/no closed questions in each grade and content area***

The kinds of questions that likely come to mind when thinking about non-yes/no closed questions are questions that use interrogative pronouns or interrogative adverbs. Here, non-yes/no questions were divided into (1) questions that ask for a noun (noun-seeking) and (2) questions that ask for an adverb or adjective (adverb/adjective-seeking).

First, the noun-seeking questions were analysed. Examples include the following:

- *What are the parts of a plant? (Grade 3, Content Area A, p. 18)*
- *What dissolves in an aqueous solution? (Grade 6, Content Area B, Volume II, p. 22)*

Table 11.3 shows that 50% of the questions in the sixth grade science textbooks were of the noun-seeking type. This ratio increased as grade level rose, from 27% in the third grade textbook. A chi-square test using grade level (4) × noun-seeking type questions (2) produced statistically significant results ( $\chi^2 = 20.691$ ,  $df = 3$ ,  $p < 0.001$ ). Compared with other grade levels, the sixth grade textbooks had a significantly higher ratio of noun-seeking questions, whereas the third grade textbook had a significantly lower ratio.

In terms of content area, the ratios of noun-seeking questions exceeded 40% for both content areas B and C. A chi-square test using content area (4) × noun-seeking type questions (2) produced statistically significant results ( $\chi^2 = 10.388$ ,  $df = 3$ ,  $p < .05$ ). Content area A had a significantly lower ratio of noun-seeking

*Table 11.3* Number of noun-seeking questions by grade and content area

<i>Content area</i>	<i>Third Grade</i>	<i>Fourth Grade</i>	<i>Fifth Grade</i>	<i>Sixth Grade</i>	<i>Total</i>
Content Area A (Living things and the environment)	17 (67)	23 (80)	28 (63)	39 (97)	107 (307)
Content Area B (Matter and energy)	13 (48)	41 (107)	51 (101)	45 (81)	150 (337)
Content Area C (The Earth and space)	2 (10)	23 (48)	19 (62)	20 (31)	64 (151)
Other	3 (5)	3 (6)	3 (5)	5 (7)	14 (23)
Total	35 (130)	90 (241)	101 (231)	109 (216)	335 (818)

The numbers in parentheses indicate the total number of questions in each grade level/content area.

questions than did the remaining content areas. A chi-square test of the number of noun-seeking questions using content area (4) × grade level (4) did not produce statistically significant results ( $\chi^2 = 14.1961$ ,  $df = 9$ ,  $ns$ ).

Next, the adjective/adverb-seeking questions were examined. Examples of such questions in the textbooks include:

- *How strong is the current that flows through the circuit?* (Grade 4, Content Area B, Volume I, p. 16)
- *How can you tell if a killifish is male or female?* (Grade 5, Content Area A, Volume I, p. 28)

The grade-level figures in Table 11.4 follow a different pattern from those in Tables 2 and 3 (yes/no and noun-seeking questions), with no visible differences in frequency across grade levels. A chi-square test using grade level (4) × adjective/adverb-seeking type questions (2) did not produce statistically significant results ( $\chi^2 = 6.489$ ,  $df = 3$ ,  $ns$ ).

In terms of content area, the results show that, whereas the ratio of adjective/adverb-seeking questions in content area A exceeded 40%, it was only 20% in content area B. A chi-square test using content area (3) × adjective/adverb-seeking type questions (2) produced statistically significant results ( $\chi^2 = 30.686$ ,  $df = 2$ ,  $p < 0.01$ ). Content area A had a significantly higher ratio of adjective/adverb-seeking questions than did the remaining content areas, whereas the ratio in content area B was significantly lower than in the remaining content areas.

A chi-square test of the frequency of adjective/adverb-seeking questions using content area (3) × grade level (4) also produced statistically significant results ( $\chi^2 =$

*Table 11.4* Adjective/adverb-seeking questions by grade and content area

<i>Content area</i>	<i>Third Grade</i>	<i>Fourth Grade</i>	<i>Fifth Grade</i>	<i>Sixth Grade</i>	<i>Total</i>
Content Area A (Living things and the environment)	28 (67)	47 (80)	16 (63)	36 (97)	127 (307)
Content Area B (Matter and energy)	10 (48)	26 (107)	27 (101)	9 (81)	72 (337)
Content Area C (The Earth and space)	3 (10)	9 (48)	34 (62)	7 (31)	53 (151)
Other	— (5)	— (6)	— (5)	— (7)	— (23)
Total	41 (130)	82 (241)	77 (231)	52 (216)	252 (818)

The numbers in parentheses indicate the total number of questions in each grade level/content area; — indicates that no such questions are included.

53.029,  $df = 6$ ,  $p < 0.01$ ). In content area A, the ratio of adjective/adverb-seeking questions in third and sixth grade textbooks was significantly higher, whereas in the fifth-grade textbooks it was significantly lower. As for content area B, the ratio of such questions in the sixth grade textbooks was significantly lower. In content area C, the ratio of such questions was significantly higher in the fifth-grade textbooks but significantly lower in the third and fourth-grade textbooks.

*Word relationships in questions in primary school science textbooks*

In this study, the questions in the Japanese primary school science textbooks were analysed using text mining. The SSRI's trend search 2015 software was used for the analysis. First, different kinds of words with their grammatical category in the text were listed and their frequencies and connections calculated. Interrogatives, such as 'how' and 'what', were then extracted from the list. Following this extraction, a physical model (spring-simulation model) was created for performing a word map by calculating the relationships between words, as in springs. The map shows high relevance words occurring more closely together (and low relevance words further apart), providing a visual image of the relationships among the words.

Figure 11.1 shows the word map of questions in the third to sixth grade science textbooks that were studied. The link between the words 'どんな (what)' and

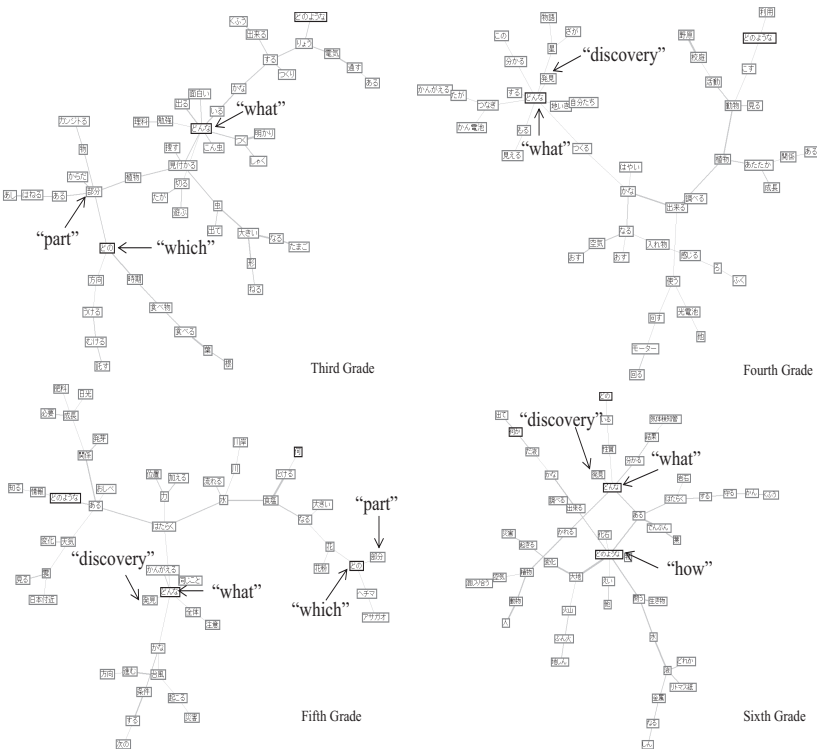


Figure 11.1 Word map of questions in third to sixth grade science textbooks

‘発見 (discovery)’ was common in questions in the fourth, fifth, and sixth grade textbooks. This suggests that one of the fundamental philosophies in Japanese primary school science is learning by discovery. Furthermore, the link between the words ‘どの (which)’ and ‘部分 (parts)’ was common in questions in the third and fifth-grade textbooks. This suggests a focus on concrete objects in primary school science. The map for questions in the sixth grade textbook has an annular part in its centre, which implies that the target for science learning in this grade is to study natural events and phenomena from multiple perspectives.

### *Questions used to review lessons in primary school science textbooks*

According to a study by Hosono (1995), teachers in Japanese primary and secondary schools identify the beginning and end of lessons as the times at which a textbook is most useful. The primary school science textbooks studied here contain questions that review each lesson, such as “*Did you learn to record the development of a butterfly? (New Science 3, Content Area A, p. 14)*”, and all are marked to help students evaluate their own progress. The third to sixth grade textbooks contained a total of 95 questions marked as review questions. One characteristic of these questions was that they all began with the phrase “Did you learn to. . . .” To analyse these questions, the verbs were extracted and sorted by content area for each grade level, as shown in Tables 11.5 to 11.8.

Tables 11.5 to 11.8 show that there were several verbs that were used only at certain grade levels, such as ‘look after’ in the third grade textbook, ‘summarise’ in the fourth-grade textbooks, and ‘conduct an experiment’ in the fifth-grade textbooks. However, there was a limited range of verbs used throughout, with many of the same verbs being used across all grade levels and content areas. One that appeared relatively frequently was the verb ‘examine (しらべる)’. Approximately 40% of all lesson-review questions contained in the third to sixth grade textbooks included this verb, which can be translated as thinking about something from various angles (Shinmura, 2008). Since the verb is used as a transitive verb with an object, the objects connected to it were extracted from the questions and sorted by grade and content area. Table 11.9 shows that the objects of these sentences included scientific terms that served as keywords in each grade and content area.

## **Discussion**

In many science classrooms, textbook questions implicitly or explicitly constrain the way teachers teach science as well as the way students learn science. In this chapter, questions found in primary school science textbooks were extracted and analysed from several perspectives. The results showed that when viewed according to grade level and content area, there were biases evident in the question patterns in particular grade levels and content areas. More appropriate grade-specific arrangements should be investigated based on grade-level advancement and domain-specific types of questions.

Table 11.5 Verbs used in lesson-review questions (third grade)

<i>Content Area A (Living things and the environment)</i>	<i>Content Area B (Matter and energy)</i>	<i>Content Area C (The earth and space)</i>
Examine and record (しらべて, 記ろくする) 4	Examine (しらべる) 3	Use and examine (つかって, しらべる) 1
Record (記ろくする) 1	Notice (見つける) 2	Use and measure (つかって, はかる) 1
Record and summarise (記ろくして, まとめる) 1	Contrive and create (くふうして, つくる) 1	
Look after without forgetting (わすれずに, せわをする) 3	Use, contrive, and create 1 (りようし, くふうして, つくる)	
Look after (せわをする) 1	Use and hit (つかって, てる) 1	
Use and observe (つかって, かんさつする) 1	Hit and compare (てるて, くらべる) 1	
	Divide (分ける) 1	
	Attach (つける) 1	
	Collect (あつめる) 1	

The numbers indicate the number of the verb in each content area.

Table 11.6 Verbs used in lesson-review questions (fourth grade)

<i>Content Area A (Living things and the environment)</i>	<i>Content Area B (Matter and energy)</i>	<i>Content Area C (The earth and space)</i>
Record (記する) 4	Examine (調べる) 7	Observe and record (観察して, 記する) 1
Use and measure (使って, はかる) 2	Pay attention to and examine (注意して, 調べる) 2	Examine and record (調べて, 記する) 1
Summarise (まとめる) 2	Build it and make it fly (つくって, とばす) 1	Pay attention to and use (注意して, 使う) 1
	Build it and make it run (つくって, 走らせる) 1	Use and measure (つかって, はかる) 1
	Make it run (走らせる) 1	
	Contrive and create (くふうして, つくる) 1	
	Use and heat (使って, 熱したり, あたためたりする) 1	
	Use and turn (使って, 回す) 1	
	Did it perfectly (きちんとできた) 1	

The numbers indicate the number of the verb in each content area.

Table 11.7 Verbs used in lesson-review questions (fifth grade)

<i>Content Area A (Living things and the environment)</i>	<i>Content Area B (Matter and energy)</i>	<i>Content Area C (The earth and space)</i>
Conduct an experiment (行う) 3	Examine (調べる) 3	Record (記す) 2
Use and observe (使って, 観察する) 2	Change and examine (変えて, 調べる) 1	Observe and record (観察して, 記す) 1
Examine (調べる) 1	Conduct an experiment (行う) 3	Examine and record (調べて, 記す) 1
	Create (つくる) 2	Release and record (流して, 調べる) 1
	Compare (くらべる) 1	
	Notice (見つける) 1	
	Filter (ろ過する) 1	
	Handle with care (注意して扱う) 1	

The numbers indicate the number of the verb in each content area.

Table 11.8 Verbs used in lesson-review questions (sixth grade)

<i>Content Area A (Living things and the environment)</i>	<i>Content Area B (Matter and energy)</i>	<i>Content Area C (The earth and space)</i>
Examine (調べる) 4	Examine (調べる) 3	Release and examine (流して, 調べる) 1
Use and examine (使って, 調べる) 2	Use and examine (使って, 調べる) 3	Follow a lead and examine (手がかりにして, 調べる) 1
	Create (つくる) 1	
	Generate (起こす) 1	
	Notice (見つける) 1	
	Sort (なかま分けする) 1	

The numbers indicate the number of the verb in each content area.

When we looked at the interrogatives used in the textbook questions, the use of the word ‘why’ was very limited. Of all the questions (818) contained in third to sixth grade textbooks, only 2% (15) contained the interrogative ‘why’. On the contrary, yes/no questions and noun-seeking questions were present in large numbers, together appearing in 76% (164/216) of the sixth grade science textbooks. Science questions cannot be answered in a simple ‘Yes/No’ form, and neither can a child answer questions using only his or her thinking processes. To use scientific language is to eschew personal feelings and fancies and aspire consistently toward objectivity and universality, in conformity with nature (Crosland,

Table 11.9 The objects of ‘examine (しらべる)’ in lesson-review questions

<i>Grade</i>	<i>Content Area A (Living things and the environment)</i>	<i>Content Area B (Matter and energy)</i>	<i>Content Area C (The earth and space)</i>
3	Body structure of an adult insect How an insect develops Body structure of an insect Body structure of a plant	Properties of the poles of a magnet Properties of steel attached to a magnet Heat of an area exposed to sunlight and how sunlight moves	Direction
4		Direction of an electric current Relationship between the electrical function and the electrical current Relationship between the electrical function and the electrical current of a photoelectric cell Changes in the volume and resistance of air or water Changes in the volume of air or water Changes in the volume of metal The way air is heated The way water is heated The way metal is heated	Location of the constellations and how the stars are positioned
5	How a child grows in a uterus	Amount of dissolved salt Amount of salt dissolved in water Weight of salt The principle for a lever to balance	Daily changes in temperature Functions of flowing water
6	Difference between exhaled air and inhaled air Ratio of the volume of oxygen or carbon dioxide Functions of sunlight How starch is changed by saliva Fundamental components of human and animal food What water is to living things	Functions of electromagnets Functions of aqueous solutions Properties of a substance dissolved in hydrochloric acid Ratio of the volume of oxygen or carbon dioxide Substances dissolved in an aqueous solution Their properties and functions	Formation of geological layers Formation of geological layers

2006). It is important for both children and teachers to note that the characteristics of science language may differ from those of other subjects even when some subjects, such as science and the Japanese language, are taught concurrently in the same language, that is, Japanese.

An analysis of lesson-review questions used in the Japanese primary school science textbooks was particularly revealing that the word ‘examine (しらべる)’ was often used. Sumida (2005) analysed responses by Japanese students to description-type questions in the TIMSS and emphasised the importance of using scientific terms to causally explain natural phenomena. The verb ‘examine’ is considered to have a low level of transitivity (Hopper & Sandra, 1980), but care should be taken when using it to causally explain natural events and phenomena. Natural science is a social activity that creates concepts and methods to explain natural events and phenomena. If we are to conduct science lessons in ways that enable children to more richly express and describe natural events and phenomena, the characteristics and importance of science language must be reflected in the textbooks.

Although science classes in primary schools include many hands-on activities, such as observations and experiments, the questions aimed at reinforcing the significance of these activities tend to be simple and limited in number. – England’s *Oxford Primary Science Dictionary* for children in KS2 (ages 7 to 11) includes simple definitions of more than 600 key scientific terms. A comparison of scientific terms used in Japan’s National Course of Study and Japanese textbooks with scientific materials prepared for children of the same age in other countries shows that science classes in Japan still have some catching up to do.

It is possible that the characteristics of the science textbook questions, identified in this chapter, variously impact different classes depending on the teacher’s emphasis and use. This chapter analysed primary school science textbook questions, but additional studies need to be conducted on questions contained in high school science textbooks. Are the characteristics of questions found in the primary school science textbooks reported here specific to only primary school science textbooks or to science textbooks in general? Are they specific to the Japanese language? Questions in science textbooks can also be considered from a language-culture perspective. Japanese primary school children study Western science in Japanese using a non-Western language. This study opens the door to discussing science education across different language-culture communities and countries.

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## **Part III**

# **Assessment and curriculum reform**



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# 12 Assessment policy in the senior physics curriculum documents of Mainland China and Hong Kong

*May May Hung Cheng and Zhi Hong Wan*

## Introduction

Over the last two decades, a good number of countries and regions have invested huge numbers of resources in reforming science education so as to nurture and prepare more competitive future generations. Mainland China and Hong Kong both published their new science education curriculum documents in the early 2000s (e.g., the Chinese Ministry of Education [MOE], 2003a, 2003b, 2003c; the Curriculum Development Council [CDC] and the Hong Kong Examinations and Assessment Authority [HKEAA], 2007a, 2007b, 2007c). A commonly recognised and emphasised factor that has a significant impact on the effectiveness of curriculum implementation is the assessment of student learning (e.g., Berry, 2008; Davison & Leung, 2009). Given the significant role played by assessment, all the updated science curriculum documents in Hong Kong and Mainland China have put forward assessment innovations.

Although Mainland China and Hong Kong are now within the same nation, they have experienced different paths of development since the 1840s when Hong Kong was occupied by the British government, and many differences can be found in their social and educational systems. With all the differences in these systems in these two regions, how will they formulate their assessment policies in their curriculum documents to facilitate the implementation of their intended new science curriculum goals? What are the major factors influencing the formulation of their assessment policies? Since assessment reform is a worldwide issue in education, answers to these questions may enrich our understanding of assessment policy in other regions.

This chapter focuses on comparing the assessment policies embedded in two current physics curriculum documents, from Mainland China and Hong Kong respectively. It begins with a review of a number of issues related to assessment based on the analysis of the two curriculum documents. Next, similarities and differences in the assessment policies of the two regions are further described. The chapter then provides an analysis of factors both within and beyond education that may explain the differences. The conclusion summarises some implications of this study.

*Forms of assessment strategies*

A few categories have been put forward in the literature to label various assessment strategies, namely formal versus informal, internal versus public, objective versus constructed-response, formative versus summative, criterion-referenced versus norm-referenced, and standardised versus non-standardised assessment (Banks, 2005). Among these categorisations, the crucial feature that differentiates summative and formative assessment is their purpose:

- formative, so that the positive achievements of a pupil may be recognised and discussed, and the appropriate next steps may be planned; and
- summative, for the recording of the overall achievement of a pupil in a systematic way (Department of Education and Science and the Welsh Office, 1988, p. 23).

Given the different purposes, there are different requirements for summative and formative assessment. Wiliam (2001) argued that the major requirement for summative assessment, especially high-stakes public assessment, is its objectivity, which can ensure relatively fair scores or grades for all students. On the contrary, the negative influences that it may have on teaching and learning tend to be justified by the need to establish such objectivity. For formative assessment, it is crucial that it can lead to successful action to support learning. In general, the weakness in its objectivity is not considered a key problem.

Although there are distinctions between summative and formative assessment, their differences are not absolute (Biggs, 1998; Cheng & Lee, 2010; Harlen, 2005). The same assessment activity can serve both formative and summative purposes. An examination given at the end of a unit evaluating students' achievement is a form of summative assessment. Meanwhile, teachers may use the results formatively to diagnose students' weaknesses so as to modify their teaching activities. While teachers can use portfolios as formative assessment to monitor students' development, the portfolios can also be used as evidence for summatively evaluating students' performance.

School-based assessment (SBA) is a well-known example of bridging formative assessment and high-stakes public summative assessment (Sadler, 1989). SBA requires teachers to observe students' performance on a broad range of objectives over an extended period of time and marks are awarded for students' performance against the objectives. These marks serve a summative purpose, as they will finally be counted in public assessment results. Moreover, SBA provides formative information to teachers so that they may better realise students' needs during the extended period of observation. It has long been an integral component of the formal senior secondary examination system in Australia, New Zealand, and the United Kingdom (Black, 2001; Sadler, 1989; Wiliam, 2001). Recently, it has also been finding its place in Asia and Africa (Davison & Leung, 2009). The implementation of SBA can help to reduce the tension between traditional high-stakes public assessment and promoting students' learning. In the literature, such conflicts have been widely commented on (e.g., Crooks,

1988; Harlen, 2005; Koretz, 1988; Linn, 2000; Wiliam, 2001; Zhan & Wan, 2010). For example, as stated by Wiliam (2001), traditional high-stakes public assessment tends to consist of timed written tests, which can only assess a limited type of competence, so there is an incentive for teachers and students to concentrate on only those aspects that are likely to be assessed. Thus, traditional high-stakes public assessment is often associated with administering repeated practice tests, training students to answer specific types of questions, and the adoption of transmission teaching methods in the classroom (Harlen, 2005). When SBA is incorporated into public assessment, a broader range of competences can be assessed and teachers are involved as assessors, reducing, to some extent, the tension between high-stakes public assessment and promoting students' learning.

Given the existence of various forms of assessment strategies, how to adopt and combine them to realise the visions of implementing assessment reform should be an important question for policymakers and is relevant for the analysis of assessment policy.

### **Context of the study: school curriculum design and public examination in Mainland China and Hong Kong**

In Hong Kong, the Curriculum Development Council (CDC) is responsible for the design of school curriculum documents. The CDC is a government-funded free-standing advisory body appointed by the Chief Executive of the Hong Kong Special Administrative Region to give advice to the government on matters relating to curriculum development for the local school system. Its members are mainly university scholars and leading school teachers. The public examinations in Hong Kong are managed by a statutory governmental body, the Hong Kong Examinations and Assessment Authority (HKEAA). Among the public examinations administered by the HKEAA, the Hong Kong diploma of secondary education (HKDSE) Examination is a high-stakes assessment undertaken by students of the new senior secondary curriculum. The results of the HKEAA examination are presented in terms of five levels, of which five is the highest and one the lowest. The Level 5 candidates with the highest performance will be awarded a 5\*\*, and the next top group 5\*. These results are high-stakes since they are used in university admission.

The leading organisation for designing school curriculum documents in Mainland China is a statutory governmental body, the Department of Basic Education of the Ministry of Education (MOE). This department commonly invites experts from universities and the National Institute of Education Sciences<sup>1</sup> to participate in the design of formal curriculum documents. The MOE includes the National Education Examinations Authority (NEEA), whose functions are similar to those of the HKEAA in Hong Kong. A very significant public examination conducted by the NEEA is the National College Entrance Examination (NCEE). Unlike the HKEAA examination, the results of the NCEE are commonly raw scores. These scores function as the major reference for university admission in Mainland China. In addition to the NCEE, there is another public examination that should

be taken by senior secondary school students, i.e. the High School Exit Examination. Since almost all students gain a pass and its score is not used for university admission, it is low-stakes.

## **Comparison of assessment policies in the current senior physics curriculum documents between Mainland China and Hong Kong**

The data reported in this chapter were obtained from the two current physics curriculum documents, Senior Physics Curriculum Standards (SPCS) (MOE, 2003a) and Physics Curriculum and Assessment Guide (PCAG) (Secondary 4–6) (CDC & HKEAA, 2007a). They are both curriculum reform documents that are still in effect in Mainland China and Hong Kong. During the process of data analysis, all the content relevant to the why, what and how dimensions of assessment (i.e. roles of assessment, content to be assessed, and assessment strategies) were identified and coded. Next, corresponding content in different dimensions was compared. The PCAG is available in both Chinese and English, but the SPCS is available only in Chinese. Therefore, SPCS content cited in this chapter has been translated from Chinese into English.

### *Roles of assessment*

Both the SPCS and PCAG include explicit and extensive statements on the roles played by assessment in science education. For example, the SPCS states in its introduction to the underlying principles that assessment is to “help students to realize their potential, grow in confidence, and develop their abilities” and also to “promote teachers to improve and innovate in their teaching practice” (MOE, 2003a, p. 2). More specifically, it argues that the assessment in physics should

- help the government, schools, teachers, students and their parents to understand senior science instruction;
- promote high school students’ all-round development;
- identify students’ needs and potential;
- help students to find their strengths and weaknesses;
- enhance students’ confidence in learning senior physics;
- encourage and guide students’ learning; and
- establish a pleasant and open environment for learning (MOE, 2003a, p. 53).

The roles played by assessment in promoting the quality of learning and teaching physics are echoed in the PCAG:

First and foremost, it [assessment] gives feedback to students, teachers, schools and parents on the effectiveness of teaching and on students’ strengths and weaknesses in learning [. . .] The most important role of assessment is in promoting learning and monitoring students’ progress.

(CDC & HKEAA, 2007a, p. 125)

A prominent difference between the two documents is the way in which they deal with the role of selecting students played by assessment. The PCAG clearly articulates that assessment “provides information to schools, school systems, government, tertiary institutions and employers to enable them to monitor standards and to *facilitate selection decisions*” (CDC & HKEAA, 2007a, p. 125, authors’ emphasis). As the PCAG further explains, “in the senior secondary years, the more public roles of assessment for certification and *selection* come to the fore. Inevitably, these imply high-stakes use of assessment since the results are typically employed to make critical decisions about individuals” (CDC & HKEAA, 2007a, p. 125). In contrast, the SPCS does not explicitly address the use of assessment results in high-stakes selection processes. The selection function of assessment can only be inferred in a statement saying that “the results of formative assessment should be considered when colleges recruit students, and the NCEE should align with this curriculum document” (MOE, 2003a, p. 55).

The emphasis on selection and high-stakes use of assessment results in Hong Kong is clear, and impacts on the learning and teaching processes in senior secondary classrooms. Although the SPCS does not emphasise the high-stakes use of assessment to the same degree, competition is keen among students in the public assessment – the assessment results directly affect whether students can gain entry to university education.

### *Content to be assessed*

Our analysis identified agreement between assessment objectives and learning targets proposed in both curriculum documents, or categorical concurrence. The SPCS classifies learning targets into three areas: Knowledge and Skills; Process and Methods; and Affect, Attitude, and Values. Corresponding to this classification of learning targets, the SPCS emphasises that “the assessment of students’ physics learning should be conducted according to three aspects: Knowledge and Skills; Process and Methods; and Affect, Attitude and Values” (MOE, 2003a, p. 53). Since there is no further elaboration in SPCS on these three aspects, we cannot evaluate the depth of consistency between assessment objectives and learning targets proposed in the SPCS.

The PCAG also categorises the learning targets into three levels: Knowledge and Understanding, Skills and Processes, and Values and Attitudes. It emphasises that “assessment practices should be used to assess comprehensively the achievement of different learning objectives including knowledge and understanding of the principles and concepts of physics, scientific skills and processes, and positive values and attitudes” (CDC & HKEAA, 2007a, p. 128). In addition, 11 elements are listed as assessment objectives. The first two are related to knowledge and understanding:

- recall and show understanding of the facts, concepts, models and principles of physics, and the relationships between different topic areas in the curriculum framework; and
- apply knowledge, concepts and principles of physics to explain phenomena and observations, and to solve problems.



The third to eighth elements relate to Skills and Processes:

- demonstrate understanding of the use of apparatus in performing experiments;
- demonstrate understanding of the methods used in the study of physics;
- present data in various forms, such as tables, graphs, charts, and diagrams, and transpose them from one form into another;
- analyse and interpret data, and draw conclusions from them;
- show understanding of the treatment of errors; and
- select, organise, and communicate scientific information clearly, precisely and logically.

The last three relate to Attitude and Values:

- show understanding of the applications of physics to daily life and the contributions of physics to the modern world;
- show awareness of the ethical, moral, social, economic and technological implications of physics, and critically evaluate physics-related issues; and
- make decisions based on the examination of evidence using knowledge and principles of physics (CDC & HKEAA, 2007a, p. 127–128).

The assessment objectives and learning targets proposed in both documents are very broad. With these broad learning targets and detailed lists of assessment objectives, teachers may be more aware of the curriculum goals, which are not only restricted to the learning of physics concepts but also involve the development of science process skills as well as the development of values and attitudes.

### *Assessment strategies*

As introduced in the previous section, a variety of learning objectives are referred to in the two curriculum documents. Both the SPCS and PCAG also suggest a broad range of assessment activities. In the SPCS, the following activities are listed: “written test, practical work, project records, behaviour observations, learning portfolios, and activity performance appraisals” (MOE, 2003a, p. 54). A separate paragraph is used to introduce the notion of a learning portfolio, which “can record the development of students in multiple aspects, can reflect both the process and outcome of students’ learning, and so can give a holistic picture of students’ learning” (MOE, 2003a, p. 54). In addition to introducing various kinds of assessment activities, the SPCS further emphasises that assessment “should combine summative and formative forms, and should not only pay attention to the outcome of students’ learning, but also record what activities students participate in, how engaged they are, and how they perform and develop in these activities” (MOE, 2003a, p. 54). However, it should be noted that the SPCS does not include an explicit definition of summative and formative assessment, or further elaboration of the relationship between them.

In the PCAG, assessment activities are divided into three types. The first is assignment. The assignment tasks include exercises, essays, designing posters or leaflets, and model construction. The second type is practical work and scientific investigation. It is suggested that “teachers can observe students’ practical skills and provide feedback on how the experiment/investigation might be improved” (CDC & HKEAA, 2007a, p. 130). The third is oral questioning. Different types of questions are recommended, including fact-finding, problem-posing, and reason-seeking questions, as well as more challenging ones that demand higher levels of thinking or allow for a variety of acceptable responses. In addition to describing different types of assessment activities, the PCAG emphasises “the need for both formative and summative assessment” (CDC & HKEAA, 2007a, p. 125) in the first paragraph of the assessment section. In the second part of the assessment section of the PCAG, a very clear definition of formative and summative assessment is provided:

“Assessment for learning” is concerned with obtaining feedback on learning and teaching, and utilising this to make learning more effective and to introduce any necessary changes to teaching strategies. We refer to this kind of assessment as ‘formative assessment’ because it is all about forming or shaping learning and teaching. Formative assessment is something that should take place on a daily basis and typically involves close attention to small “chunks” of learning.

“Assessment of learning” is concerned with determining progress in learning, and is referred to as ‘summative assessment’ because it is all about summarising how much learning has taken place. Summative assessment is normally undertaken at the conclusion of a significant period of instruction (e.g. the end of the year, or at the end of a key stage of schooling) and reviews much larger “chunks” of learning.

(CDC & HKEAA, 2007a, p. 126)

The PCAG goes on to state, “In practice, a sharp distinction between formative and summative assessment cannot always be made, because the same assessment can in some circumstances serve both formative and summative purposes” (CDC & HKEAA, 2007a, p. 126).

In addition, internal and public assessments are explicitly defined in the PCAG: “Internal assessment refers to the assessment practices that teachers and schools employ as part of the ongoing learning and teaching process during the three years of senior secondary studies” (CDC & HKEAA, 2007a, p. 127). On the contrary, “public assessment refers to the assessment conducted as part of the assessment process in place for all schools” (CDC & HKEAA, 2007a, p. 127). For internal assessment, the PCAG introduces eight guiding principles and specific assessment activities. Five guiding principles for public assessment are also provided. Additionally, the outline of the Senior Physics HKDSE Examination is provided. As indicated in Table 12.1, this examination has two components – i.e., public examinations and SBA. In SBA, students’ performance is reflected in two kinds of tasks: practice related and non-practice related. SBA, as described in the

*Table 12.1* An outline of the public assessment design of senior secondary physics in Hong Kong (CDC & HKEAA, 2007a)

<i>Component</i>	<i>Outline</i>	<i>Weighting</i>	<i>Duration</i>
Public examination	Paper 1 – Compulsory Part	60%	2½ hours
	Paper 2 – Elective Part (a choice of two out of four elective topics)	20%	1 hour
SBA	Practical related tasks and non-practical related tasks	20%	

PCAG, performs the particular function of bridging the formative assessment and the summative high-stakes assessment.

Since SBA, which can serve to promote formative assessment in the classroom, is incorporated into the public assessment in Hong Kong, the alignment between curriculum and assessment that can be found in this document relates not only to internal assessment, but is extended to external assessment.

### **A summary of the similarities and differences between two documents**

As reflected in the comparison, there are some similarities between the assessment policies, including promoting the formative role of assessment for improving teaching and learning physics, the alignment between the suggested content for assessment, and the learning outcomes included in the curriculum standards, advocating the integration of formative assessment and summative assessment, and the different types of assessment activities. Despite the similarities, a number of differences are also identified.

- The summative function of selecting students is explicitly argued in the PCAG, while this function is not made as explicit in the SPCS.
- Comparatively, the PCAG provides a more detailed discussion on the concepts of and the relations between formative and summative assessment.
- The description of internal assessment and public assessment in the SPCS is not as structured as that in the PCAG.
- In the PCAG, SBA is taken as part of the public assessment, which bridges the formative and summative assessment components. On the contrary, similar innovation is not found in the SPCS.

Among these differences, the last one seems to be fundamental. It has been mentioned that there are tensions between summative functions or

traditional high-stakes public assessment and formative functions or promoting students' learning, and SBA can serve to reduce this tension. Through the implementation of the SBA, a better balance between the functions of assessment as selection and promoting learning may be achieved. In the PCAG, SBA is a special form of assessment which bridges formative and summative assessment and is conducted within the schools with the results used in external assessment. With the introduction of SBA, it is necessary for the PCAG to include a detailed discussion on formative, summative, internal and public assessment so as to help readers understand this special form of assessment. On the contrary, the SPCT does not introduce similar innovations or SBA. Thus, the conflicts between high-stake public assessment and promoting students' learning have not been reduced. Consequently, the assessment role of selecting students is not explicitly emphasised. Without the introduction of components such as SBA in the SPCT, a description or distinction of formative, summative, school-based and public assessment is not deemed necessary.

### **Explaining the differences in assessment policies in the current senior physics curriculum documents of Mainland China and Hong Kong**

On the basis of the earlier discussion, we may find that although the designers of the senior physics curriculum documents in Mainland China and Hong Kong used the same set of assessment tools, shared common visions of using assessment to promote learning and teaching, and had a similar intention to integrate formative assessment and summative assessment, they made different decisions on how to address the tensions in relation to high-stakes public assessment in the formal curriculum documents. The introduction of SBA and the effort to link summative and formative functions is clear in the PCGA in Hong Kong. These decisions might in turn lead to differences in other aspects of the documents. The context underpinning these decisions is elaborated in the following sections.

#### *Organisations involved in designing curriculum documents*

The design of the PCAG involves two organisations in Hong Kong. They are the CDC and the HKEAA. These two organisations cooperated in this round of reform. They put forward innovative policies for assessment practice inside schools and introduced the changes into public assessment, achieving a better alignment between the new curriculum goals and assessment practices.

Although the assessment policies are included in the SPCS, the curriculum document did not reflect that the NEEA has joined the design of this curriculum reform document. It is, therefore, not surprising to note that the designers of the SPCS have not included policies that can introduce concrete innovations into public assessment.

### *Constraints of enhancing the validity of the results generated in formative assessment*

When integrating formative assessment into high-stakes public assessment, in addition to providing detailed guidelines, assessment criteria and exemplars, the assessment authority should adopt relevant measures to enhance the effectiveness and validity of the assessment innovation (SBA). For example, every year since 2005, the HKEAA has provided a series of professional development training sessions to familiarise teachers with how to conduct SBA of their subject(s). District coordinators have been appointed by the HKEAA to support schools in the conduct of SBA for individual subjects. Strategies have been developed to moderate SBA marks submitted by different schools to iron out possible differences among schools in marking standards. All these measures have a very high demand on the funding provided by government and the knowledge and skills of colleagues in the HKEAA as well as schools. Hong Kong is a developed economy and is experienced in providing pertinent teacher professional development support. Besides, it had already accumulated the experience of conducting formative assessment in some subjects before this new curriculum reform (Berry, 2011).

In contrast, a dramatic imbalance in economic development exists among different regions in Mainland China. There is also a lack of experience of implementing formative assessment. These contexts add to the difficulty of implementing new assessment innovations such as SBA.

### *The presentation of the results of public assessment*

As introduced earlier, Mainland China and Hong Kong adopt different ways of presenting the results of public assessment. The NCEE uses raw scores, which play a crucial role in the complex university admission system in Mainland China. Since the raw score is used, even a difference as small as one point in the students' score in one subject will be directly reflected in their total score, which may in turn influence entrance into prestigious universities. If the results of assessment strategies such as SBA are to be added into the NCEE scores, a high requirement for the objectivity of the assessment result will also be expected by the public.

A commonly recognised challenge to SBA is its weakness in objectivity (Hill, Brown, Rowe, & Turner, 1997). Although statistical strategies are developed to moderate SBA scores to enhance comparability at the school level, it is still rather difficult to ensure a very high level of comparability when the design and the context of assessment tasks and individual teachers' interpretations of the assessment criteria may vary. Therefore, SBA is usually considered as less objective and trustworthy than standardised tests (Reeves, Boyle, & Christie, 2001) and so can be a challenge to public assessment, in particular to highly competitive systems like the NCEE in Mainland China. This may explain the reasons for not finding SBA in the SPCS.

In contrast to the NCEE, the HKDSE examination provides grades instead of raw scores. As a result, there is a relatively lower possibility of the change of several points in the raw scores of a subject changing a student's result in the university admission process. Comparatively speaking, the demand for point-by-point precision in the allocation of scores for the HKDSE is not as high as that of the NCEE.

## **Conclusions and implications**

This chapter has identified both similarities and differences in the two current physics curriculum documents of Mainland China and Hong Kong. Among all the differences identified, the implementation of SBA seems to be fundamental. It is explained that these differences may be caused by a number of subcultural factors in these two areas, including the organisations involved in designing the curriculum documents, practical constraints of enhancing the validity of the results generated in formative assessment, and ways of presenting the results of public assessment. Drawing from these conclusions, a number of implications can be identified.

Some challenges for implementing SBA have been discussed in the literature, including (i) the weakness in the objectivity of its result, which is caused by the variations among individual teachers' interpretations of the assessment criteria and their judgments of students' performance (Hill et al., 1997; Reeves et al., 2001); (ii) the high requirements that SBA places on teachers' expertise in assessment and teaching (Yip & Cheung, 2005); and (iii) the increased workload for teachers and students (Board of Studies, 1998; Cheung, 2001). These challenges are common at the practical or technical level. More broadly, the constraining factors for implementing SBA elicited in this paper are situated in the subcultural social and educational systems, which supplements the existing theories related to SBA.

Assessment is an integral part of the curriculum, pedagogy, and assessment cycle. Close alignment between curriculum and assessment should be achieved by curriculum developers. However, such success depends on a number of contextual factors. As indicated in this chapter, although the designers of the new senior physics curriculum documents in Mainland China and Hong Kong suggested the same set of assessment tools, shared similar visions of using assessment to promote learning and teaching, and promoted the integration of formative assessment and summative assessment, the alignment in Mainland China's SPCS is within the internal assessment, while in Hong Kong the alignment is extended into the high-stakes public assessment in the PCAG through SBA. Clearly, there are differences embedded in the social educational systems of the two regions. Researchers and policymakers should therefore not only pay attention to the similarities or differences in curriculum and assessment in different locations but also understand how the strategies adopted may or may not be consistent with the social and educational systems in their own regions.

Countries in East Asia have a strong examination culture (Zhan & Wan, 2010). Within this culture, it is challenging to promote and nurture a culture of formative assessment if teachers and the public do not see any relationship with public assessment. As there are competing demands on curriculum and teaching time at the senior secondary levels, such assessment innovation cannot be sustained – even if it is encouraged by the government, teacher training, and other resources are provided, and teachers have strong, active intentions. Senior secondary teachers may be under pressure from other colleagues, students, and their guardians, to give up their attempts at change.

Hong Kong had an unsuccessful experience when implementing the Target-oriented Curriculum Initiative in the 1990s (Carless, 1997). On the contrary, when formative assessment practice is integrated with public assessment, it at least reduces some external pressure preventing teachers from implementing the assessment innovation at the classroom level. Therefore, although the integration of SBA into public assessment may not be a perfect solution, this strategy can be considered as a workable one under circumstances where the influence of the examination culture is still strong. For Hong Kong, it is important that the HKEAA gives clear support for SBA in the coming decade if efforts from the education community are to be sustained. Otherwise, teachers may easily give up on the innovation, anticipating that SBA may be abolished at any time. The experience of implementing SBA in Hong Kong, as described in this chapter, may provide one of the solutions for other countries in East Asia to implement assessment innovations in the context of a strong examination culture.

## Note

1 The National Institute of Education Sciences is a research arm of the Ministry of Education and the only national-level comprehensive education research institution in China. Its major functions include advising on policy, advancing theoretical innovation, and guiding local practices.

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# 13 Pre-service science teachers' implementation of assessment for students' learning

*Hye-Eun Chu and Chee Leong Wong*

## Introduction

Formative assessment, or assessment for learning, may refer to any activities used by teachers to assist students to realise where they are in their learning, and how they should continue to learn from there (Black & Wiliam, 1998). Summative assessment, or assessment of learning, is the use of activities to measure, record and report on students' levels of learning with respect to the learning outcomes (Harlen, 2005). On the other hand, assessment as learning 'seeks to help students take responsibility for their own learning and so build metacognition in the learner' (Corrigan, Bunting, Jones, & Gunstone, 2013, p. 2). In other words, it refers to the use of activities which enable students to continue with their own learning. For example, self and peer assessment help students to reflect on their own learning processes and identify their strengths and needs. As novices, pre-service teachers may not be sure about the different 'modes' of assessment and how to effectively implement assessment for learning.

Digital technologies have been incorporated into many physics education initiatives to support assessment for learning. For example, the Assessing-to-Learn (A2L) project brought together a strategic approach to learning, instruction, and communication, seeking to integrate formative assessment and instruction in high school and college classrooms (Dufresne & Gerace, 2004). The project had four goals: (1) to facilitate the use of assessment for learning, (2) to use technology that enables more interactions within classrooms, (3) to help teachers assess students' cognitive development, and (4) to study the role of technology within the classroom and the use of assessments in student learning, reasoning, and problem solving. Although the programme consisted of learning activities and problem-solving tasks, Dufresne and Gerace explained that there is no simple procedure for implementing assessment for learning. The implementation of formative assessment is dependent on the learning priorities of teachers and the academic abilities of students. For instance, specific and immediate feedback could be given to low-achieving students, while guided questions or delayed feedback for self-regulated learning could be given to high-achieving students (Cauley & McMillan, 2010; Hattie & Timperley, 2007).

In Singapore, students can assess their own learning by practising the 'ten-years-series' examination questions. Similarly, teachers may assess the learning of

students by using these examination questions in any form of assessment, both formative and summative. However, in an opening address by Mr Heng Swee Keat, minister for education (Singapore) at the 2014 International Association for Educational Assessment Conference, he announced that there are new projects on the use of Information and Communications Technology in assessment. In his words, “We are keen to learn from others how 21st century skills can be assessed and how we can better use technology to innovate assessment, be it assessment for Learning, Assessment of Learning or Assessment as Learning” (Heng, 2014). He also provided three suggestions regarding assessment: assessment innovations must fulfil a specific purpose, they must be in the best interests of the students and their learning, and they must be supported by established assessment principles.

At the time, the Singapore Ministry of Education was also preparing a new curriculum to be implemented in 2015 (C2015). This new curriculum emphasises the important role assessment plays in students’ holistic development of knowledge, skills, values, and attitudes. However, the current emphasis on STEM education has not been highlighted in the new curriculum for government schools compared to its emphasis in some independent schools. Even though the C2015 curriculum does not emphasise STEM education in mainstream schools, the direction that Singapore science education is heading in is certainly supportive of STEM education at the primary and secondary school levels. However, the speed of recent changes means that we cannot expect assessment innovation to be incorporated into pre-service teacher education without difficulty. Pre-service teachers may adopt alternative definitions of formative assessment, or have inaccurate beliefs or perceptions of their implementation of formative assessment at the beginning of their teaching practice.

The aim of this study was to develop an effective AforL programme for pre-service science teachers based on the findings from a recent investigation of how pre-service science teachers implement formative assessment during their practicum teaching. Importantly, pre-service teachers’ beliefs and perceptions of their implementation of formative assessment may affect their future implementation of formative assessment. Thus, two research questions guided this study: (1) What do pre-service science teachers know about assessment for learning or formative assessment? (2) What are the perceptions or beliefs of pre-service science teachers regarding their implementation of assessment for learning during their practicum teaching?

## **The implementation of formative assessment**

The term formative assessment does not have a precise, agreed definition (Black & Wiliam, 1998). There is also no agreement on how formative assessment should be implemented. For example, Bell and Cowie (2001) define formative assessment as ‘the process used by teachers and students to recognise and respond to student learning in order to enhance that learning, during the learning’ (p. 536). This definition could include assessment of students’ ideas in a formal or informal context. Alternatively, formative assessment has been defined as a process

of appraising, judging or evaluating students' work or performance and using it to shape and improve students' competence (Gipps, 1994). That is, it may involve formally assessing students' work. However, the main ideas of formative assessment are to evaluate students' cognitive abilities or skills with the intention of improving students' learning. Educational researchers' and science teachers' implementation of formative assessment may include additional characteristics that are not specified in these definitions.

A study by Bell and Cowie (2001) in New Zealand indicates that formative assessment has the following ten characteristics: it may (1) be responsive, (2) draw on a variety of sources of evidence, (3) be a tacit process, (4) use the teacher's professional knowledge and experiences, (5) be integrated within teaching and learning, (6) be inclusive of both teachers and students, (7) inform students' learning and teachers' teaching, (8) be contextualised, (9) create dilemmas (faced by teachers) that have no obvious solution, and (10) rely on students' disclosures. However, we do not always find all these characteristics in formative assessment. For example, Black, Harrison, Lee, Marshall, and Wiliam (2004) outlined the following practices of formative assessment: questioning, feedback with comments and without grades, peer assessment and self-assessment, and formative use of summative tests. Essentially, effective questioning should be an important aspect of the classroom discourse when students and teachers are engaged in formative assessment. Nevertheless, science teachers may not be adequately trained in effective questioning. In general, questioning techniques to scaffold student thinking could include Socratic questioning, verbal jigsaws, semantic tapestries, and framing (Chin, 2007).

In traditional teaching methods, science teachers ask questions to check students' knowledge (Initiation), listen to students' responses (Response), and evaluate their responses (Evaluation). This is known as the I-R-E structure (Mehan, 1979). An alternative is the I-R-F framework – initiation, response, and follow-up (Sinclair & Coulthard, 1975). Currently, in constructivist-based approaches, teachers pose a series of questions to evaluate students' thinking instead of lower-order recall knowledge. In other words, it involves inquiry-based teaching in which teachers use reflective questions and maintain silence for a while to foster students' thinking (van Zee & Minstrell, 1997). Mortimer and Scott (2003), therefore, developed the IRFRF chain (teacher initiation – student response – teacher feedback – student response – teacher feedback) such that there is a dialogic interaction whereby teachers can evaluate their students' thinking by encouraging them to elaborate on their ideas or responses. This series of questions can be considered as a form of formative assessment because teachers can assess students' competence in thinking and then implement further learning steps.

Around the world, formative assessment is increasingly specified in educational policy documents on assessment and in the professional development of teachers. However, science teachers need to have a well-structured model and have deeper understanding of formative assessment for effective implementation. Importantly, it is not clear to what extent pre-service teachers are able to adequately

implement formative assessment that is inquiry-based. However, in a study conducted by Ralph (1999), pre-service teachers in Canada were able to improve the clarity of their questions, increase the wait time for students' responses, and pose questions to students with a wide range of abilities. In a more recent study in the United States, Weiland, Hudson, and Amador (2014) argued that pre-service teachers can develop their questioning practice through weekly practice and reflection within the context of teacher-student interactions.

Previous studies have indicated that substantial learning gains are possible when teachers make the effort to embed formative assessment into their teaching practices (Black & Atkin, 1996; Black & Wiliam, 1998; Crooks, 1988). However, educational researchers have found that high-stakes national examinations can negatively impact effective implementation of formative assessment (Wiliam, Lee, Harrison, & Black, 2004). For instance, to help students achieve higher scores on these tests, teachers may focus on rote recall of the test content. Admittedly, teachers cannot avoid the pressure of such examinations on their teaching, but Kang (2007) as well as Otero and Nathan (2008) emphasised that teachers' beliefs about teaching and learning are the most important factor influencing their teaching practices. To implement formative assessment in their teaching practices, teachers need to value teaching for understanding. More importantly, embedding a formative assessment focus in inquiry-based activities or classroom discourse may enhance students' learning and improve their academic achievement. This justifies the need to investigate how Singaporean pre-service teachers incorporate assessment for learning.

## **Methodology**

This was an action research study conducted in the National Institute of Education, Singapore. The AforL pre-service science teacher programme was introduced and evaluated using data collected during the lectures in an assessment module.

### ***Participants***

Sixty pre-service science/physics teachers enrolled in the post-graduate diploma in education (PGDE) programme participated in this research. The PGDE programme aims to prepare university graduates to become secondary school teachers. It is a one-year pre-service teacher-training programme. (Pre-service teachers specialising in physical education attend a two-year PGDE programme.) The pre-service teachers had relevant content knowledge from their undergraduate education, and most were physics or engineering graduates. Some pre-service teachers were not fresh from undergraduate study, but had working experience in different professions such as engineering and computer programming. Currently, all teacher candidates are required to spend half a year as a contract teacher at an allocated school before attending the PGDE programme. In addition, near the end of the one-year PGDE programme, the

pre-service teachers are usually attached to schools in Singapore for a practicum experience of 10 weeks.

### *Assessment for learning programme for pre-service science teachers*

The AforL programme focuses on the function and timing of assessment for learning. This programme provides information that the pre-service teachers can use to make judgments during a class, or when planning lessons (Black & Wiliam, 1998; Shepard, 2000). In essence, work in the AforL module focuses on classroom interactions among students as well as between the students and teacher.

In the AforL programme, pre-service science teachers are provided with a definition of inquiry-based teaching and learning. The two extremes of open-inquiry and closed-inquiry-based teaching and learning can be determined by whether teachers or students have the authority to decide inquiry questions, collect and analyse evidence, make connections between their observations or analysis findings of scientific concepts, and present their explanations (Chin, 2007; Magee & Flessner, 2012). The pre-service teachers are also introduced to the role of questioning skills (Chin, 2007) during lectures connected to the possession of authority in the science classroom. The differences between the I-R-E and I-R-F-R-F chains are discussed through comparison of traditional and constructivist teaching approaches. Questioning skills are emphasised because they can help pre-service teachers incorporate inquiry into learning scientific concepts during lessons, drawing on classroom conversations.

The pre-service science teacher AforL education programme is conducted 4 weeks before the pre-service teachers go for their 10-week teaching practicum. In this module, pre-service teachers are asked to develop their questioning skills by incorporating different pedagogical tools, such as demonstrations using the Predict – Observe – Explain (POE) strategy, concept cartoons, and diagnostic instruments in their lessons. At the same time, the reasons for these tools and strategies are emphasised through the ‘AforL cycle’. The AforL cycle includes (1) obtaining information on students’ ideas and reasoning in the topic of instruction, (2) identifying students’ understanding of the concepts, and (3) deciding on teachers’ actions to help further develop students’ understandings (Treagust, Jacobowitz, Gallagher, & Parker, 2001).

During the AforL module, pre-service teachers are guided to design their own formative assessment approach over four to five weeks, with a two-hour tutorial lesson each week. First, assessment for learning, assessment as learning, and assessment of learning are compared and the pre-service teachers are asked to identify the purposes, rationale, and methods associated with each type of assessment. This is intended to help them understand the characteristics of formative assessment. Second, the AforL module was designed based on the idea that formative assessment needs the ‘attention’ of disciplinary substance (Coffey, Hammer, Levin, & Grant, 2011), and it should be integrated

throughout classroom activity, and not restricted to specially designated ‘assessment activities’.

### *Data collection and analysis*

At the beginning of the module, an open-ended questionnaire was administered to each group of pre-service teachers taking part in this study to identify their prior understanding of formative assessment. After the module, we analysed the pre-service teachers’ individual reflection writing about their implementation of formative assessment in their teaching.

### *Open-ended questionnaire before the lecture*

Before the module on formative assessment, the pre-service teachers in groups of four were asked to answer the following three questions:

- (1) What do you know about AforL, Assessment as Learning (AasL) and Assessment of Learning (AofL)?
- (2) When can you use the three different types of assessment during your lessons?
- (3) What are examples of the different types of assessment?

The pre-service teachers discussed the aforementioned questions in their groups and then answered the questions. The group discussion as a metacognitive exercise prior to learning new pedagogical approaches had been conducted throughout the semester. The pre-service teachers knew that this was a time for them to share what they knew about the pedagogical topic.

### *Individual written reflection*

After the pre-service teachers’ implementation of lessons in school with a specific focus on formative assessment, they wrote reflections on their practicum lessons, specifically considering three aspects:

- (1) What was the effectiveness of the AforL tools/strategies?
- (2) What were some of the students’ difficulties in the lesson?
- (3) How did they help students overcome their difficulties during the lesson?

The written reflections were analysed as being positive, negative, or neutral regarding their implementation of assessment for learning during their practicum teaching experience. Eight of the pre-service teachers were also interviewed to investigate in more depth their views on the assessment strategies which they adopted during their lessons. The interview questions were “What do you think of your AforL approaches and their effects on students’ learning?”, “How will you improve your assessment-embedded teaching?”, and “Are you going to use the same assessment approaches again?”

### *Data analysis*

The pre-service teachers' responses to the open-ended questionnaires before the module were categorised and the percentages of each category were calculated to show their prior understanding of formative assessment. To identify how the AforL programme for pre-service science teachers influenced their teaching practices, their individual written reflections were also analysed and the proportion of positive, negative, or neutral responses was computed. Also, the interviews were transcribed and some of the interview excerpts were extracted to be used as supporting examples of teachers' responses to positive, neutral, and negative responses in their reflection writing analysis. As this is an example of action research, the teacher-researcher kept reflective notes that could help to further analyse the data.

### **Findings and discussion**

The pre-service teachers were divided into 15 groups of 4. The responses to the open-ended questionnaire were analysed to investigate the participants' prior understandings of formative assessment before the module.

#### *Pre-service teachers' prior understanding of assessment*

All groups showed clear understanding of learning assessment. Most of them mentioned summative assessment and checking students' knowledge. For AforL, seven groups (12%) and for AasL only two groups (3%), showed acceptable understanding. Six groups (10%) displayed confusion between AofL and AforL. The pre-service teachers were aware that both could be continuous assessment and that it enabled teachers and students to keep track of their learning. In Singapore, teachers are more familiar with continuous assessment (monthly based tests) and semestral assessment (SA or term tests). In a sense, both continuous assessment and SA can be used as assessment for learning because teachers provide feedback to students in their answer scripts. Thus, these assessments can help to address students' alternative conceptions and prepare them for the final examination. However, teachers may not use the assessment information for planning and redesigning their lesson activities to provide students with opportunities for constructing their prior knowledge into much closer scientific knowledge or for designing lessons for students to practice skills of self-regulation, metacognition, collaboration and communication during his/her ongoing lessons. The group responses helped the pre-service teachers to identify the gaps in their own understanding of the different types of assessment.

#### *The timing of formative assessment*

Most of the pre-service teachers believed that feedback on students' test scores may be part of AforL. In addition, about half of the groups (7 of 15) also

mentioned that AforL can be conducted at the beginning of a lesson for diagnostic purposes and at the end of a lesson to make sure students have understood the scientific concepts, rather than throughout a lesson to focus on students' learning as a continuous learning path. On the other hand, pre-service teachers could not answer properly about the notion of AasL. Only two groups were able to link this assessment with self/peer assessment and designing assessment rubrics that could be used during a semester. These two groups used project-based assessment related to students' use of rubric criteria and descriptors to assess and improve their own project work.

### *Pre-service teachers' examples of formative assessment*

About half of the groups (7 of 15) also mentioned project work as an example of AforL because students have to plan their project, carry it out, collect and analyse their findings, and then refine their processes based on their reflections. However, the pre-service teachers did not mention how these teaching and learning processes could be used to assess and then inform students' ongoing learning. Moreover, most pre-service teachers provided examples of AforL such as pop quizzes, tests, and teachers' feedback. They also mentioned teachers' questioning because another lecturer in the previous semester's course had emphasised the importance of questioning skills in formative assessment. In other words, the pre-service teachers recognised the role of conversational assessment to evaluate students' thinking and correct any possible alternative conceptions (Morrison & Lederman, 2003).

Nevertheless, the pre-service teachers' understanding of assessment may have been due to their half-year experience of contract teaching in a secondary school in Singapore.

### *Reflections of formative assessment during practicum teaching*

The pre-service teachers' written reflections during their practicum teaching were analysed to investigate the impact of the AforL programme on their teaching practice. After the pre-service teachers had gone through the AforL program in the assessment module, they were expected to embed formative assessment during their practicum teaching. They were asked to follow the assessment cycle (identify students' ideas – analyse the responses – decide teacher actions on the spot or design activities for the next lesson) and use different assessment approaches to find out students' ideas and understanding throughout the lessons taking into consideration inquiry-based teaching and learning approaches.

The pre-service teachers adopted six different types of AforL strategies during their practicum teaching (see Table 13.1). The most commonly implemented strategies were Predict-Observe-Explain (POE) (22%) and diagnostic tests (20%). Some pre-service teachers used concept cartoons (17%) or implemented both POE using concept cartoons (30%) as a continuous assessment-embedded inquiry teaching approach. The pre-service teachers showed that the



*Table 13.1* AforL strategies implemented during the teaching practicum and pre-service teachers' views about the effectiveness of these strategies (% in parenthesis)

<i>AforL strategies</i>	<i>Number of students (n = 60)</i>	<i>Views about the strategies</i>		
		<i>Positive</i>	<i>Neutral</i>	<i>Negative</i>
POE	13(22)	12(20)	1(2)	-
Teachers' questioning	7 (12)	4(7)	1(2)	2(3)
Concept cartoons and classroom discussions	10(17)	3(5)	-	7(12)
POE using concept cartoons	8(13)	5(8)	1(2)	2(3)
Diagnostic test	12(20)	12(20)	-	-
Worksheets	8(13)	7(12)	1(2)	-
STEM approach and discussions	2 (3)	2(2)	-	-
Total	60 (100)	45(74)	4(8)	11(18)

strategies were significantly closer to constructivist and inquiry-based teaching. However, they also showed more negative responses about their strategies when they planned classroom discourse as a strategy (positive response: 5% and negative response 12%). Two pre-service teachers reported using strategies that we defined as a 'STEM approach'. One of them asked students to design a straw structure for a safe 'egg drop' before teaching impulse-momentum theory. The other asked students to design a cooling bag to keep ice cream cold after they had learned about thermal physics. These two pre-service teachers expressed strong positive views in their interviews that applying scientific concepts in real-world contexts helps students learn the concepts.

In this study, we also attempted to understand the pre-service teachers' views on the effectiveness of their use of formative assessment. In general, the positive response (74% of the participants) means that the pre-service teachers perceived that the strategies implemented in the teaching practice were effective for diagnosing students' learning and for them to connect their teaching and feedback to help students' learning. On the other hand, 18% of the participating pre-service teachers reported that their strategies were not effective during their lessons. A few (8%) seemed neutral about the effectiveness of their implementations of formative assessment.

### *Three kinds of responses from the pre-service teachers*

Based on the findings from the reflection writing and interviews, the pre-service teachers indicated that the formative assessment strategies were most effective

when they incorporated concept cartoons, questioning methods and context-based activities. In their reflections, they opined that these strategies can be further modified. Their responses were classified as three kinds: positive, negative, and neutral.

In terms of positive responses, they commonly used words such as ‘effective’, ‘continuously used’, and ‘help’. For example, some responded that “The AforL was very effective for students’ learning”, “The implemented AforL tools/strategies will be continuously used in my teaching”, and “I would like to improve my AforL-embedded teaching because it really helps to give students appropriate feedback”. These are indications that the pre-service teachers believed or perceived that their teaching was effective and that they would continue to implement similar strategies. Their positive views tended to be related to strategies such as using diagnostic tests (20%), POE (20%), and worksheets (13%).

The pre-service teachers’ negative responses were identified by their use of words such as ‘not very effective’ and ‘will not use’. For example, some wrote along the lines of, ‘If I have the opportunity to revise my lesson, I will not use the same AforL strategies because it will not work effectively. . .’ The negative beliefs were usually identified when they implemented formative assessment based on discourse.

Regarding the neutral responses, some pre-service teachers used words such as ‘but’ or elaborated that “it was very time consuming”. For instance, some responded, “The implemented strategies went well and helped me to understand the students’ level of understanding but it was very time consuming”. Alternatively, one answered, “I will revise the implemented AforL and use it when it is needed”.

In general, the pre-service teachers were able to select strategies that were embedded in their teaching to diagnose students’ learning process. When it was not aligned with their classroom situations, or when the scope of AforL included classroom discourse, the pre-service teachers’ responses indicated negative views or beliefs. Also, many pre-service teachers believed that AforL was informal assessment that could be regarded as a way to save time and which could be replaced with drill and practice. However, this problem may not be easily resolved because pre-service teachers also learnt by drill and practice when they were students in secondary school. Therefore, pre-service teachers could prefer using the same teaching method that they experienced as students to prepare for high-stakes examinations (Caleon, Tan, & Cho, 2017).

## **Conclusions and limitations**

We believe that this study will contribute to helping science educators, lecturers and education policymakers to understand pre-service teachers’ conceptions and implementations of formative assessment.

First, many believed that formative assessment can be conducted at the beginning of a lesson for diagnostic purposes and at the end of a lesson to make sure students have understood the scientific concepts, rather than continuously focusing on students’ learning and improving their reasoning.

Second, those pre-service teachers who implemented formative assessment based on discourse faced difficulties conducting the lesson, and gave negative responses regarding their implementations of AforL in the classroom contexts.

Third, the pre-service teachers were more comfortable implementing formative assessment by using traditional teaching approaches such as diagnostic tests and worksheets.

Interestingly, only two pre-service teachers conducted the STEM approach with discussions, and both expressed strong beliefs that it really helped the students to make connection with their understanding. Specifically, they were able to guide the students to reflect on their design experiments (egg drop) and learn the concept of impulse.

Nevertheless, there are several limitations to this action research. It was a small study with a sample size of only 60 pre-service teachers. However, this research gives us an indication of pre-service teachers' difficulties in embedding formative assessment in inquiry-based teaching and learning in their lessons. The research findings provide us with information on how to improve the four- to five-week module on AforL in pre-service science teacher training programmes.

The AforL programme should be improved by guiding pre-service teachers to reflect on their teaching through the use of videos (Gotwals & Birmingham, 2016; Seidel, Stürmer, Blomberg, Kobarg, & Schwindt, 2011; Star & Strickland, 2008). During lectures, the lecturer encouraged the pre-service teachers to analyse videos that showed different approaches to formative assessment in school. The subsequent approach should have been conducted for pre-service teachers to reflect on their lessons in greater depth if their microteaching practice or actual lessons in school were videotaped. Interestingly, in a study conducted by Gotwals and Birmingham (2016), pre-service teachers were found to have more productive reflections by observing videos of their own and others' teaching.

The high-stakes assessments at the secondary level indicate directly what is valued and emphasised as science in the classroom (Jones & Bunting, 2013). We should not expect all school students to appreciate inquiry-based activities and classroom discourse during formative assessment. Currently, a considerable number of Singapore students<sup>1</sup> have utilitarian, performance, and achievement motives in learning science (Cheng & Wan, 2016). Thus, it is still important to explain to students why science teachers should engage them in inquiry-based activities and the use of questioning methods in the classroom. One potential issue is that students may not understand or agree with the rationale of a teacher's approach in posing questions. Some students fix their mind on thinking that they do not understand the concept in the first place and they are unable to benefit from inquiry-based activities. Many students also prefer teachers to present the answers directly and immediately. As an analogy, students may prefer an 'instant answer' just like the 'instant noodle' or 'instant coffee' that they enjoy. In short, the use of questioning methods in the classroom may be perceived as a waste of time. It may not be easy to convince these students of the value of the inquiry-based approach in learning.

On the other hand, pre-service teachers usually have limited knowledge of correct concepts in science. Therefore, some may feel that it is of higher priority to develop content knowledge for classroom learning, especially in contexts where content knowledge continues to be valued in high-stakes assessments. Nevertheless, in a study conducted by Galili and Lehari (2006), even experienced physics teachers were unable to provide correct definitions of physics concepts. Thus, it is important to provide more resources on discourse-based formative assessment that can guide pre-service teachers to implement inquiry-based activities effectively with minimal preparation time. In the future, the AforL programme for pre-service teachers could also be refined to help students' learning progression on content knowledge and reasoning (especially declarative knowledge and reasoning) in shorter periods (within three to four lessons).

Last but not least, pre-service teachers' implementation of formative assessment in classroom teaching is likely influenced by the experienced teachers or the types of students in the allocated secondary schools. Experienced teachers could recommend how formative assessment should be implemented based on their experience in the secondary schools – but this assumes that the experienced teachers not only value formative assessment, but can explicitly link their views to their practice. However, students may have different views on the effectiveness of pre-service teachers' classroom teaching. Students' feedback (formal or informal) on pre-service teachers' lessons may also be dependent on the rapport between the pre-service teacher and the students. Therefore, the pre-service teachers' perceptions of their implementations of formative assessment in the classroom may be indicative of multiple complex factors, including the relationships they were able to establish during the short time they spent in the students' classroom. As a result, further research is still needed to incorporate assessment innovation into pre-service teacher education.

## Note

1 Students studying in Singapore may come from Hong Kong, Taiwan, South Korea, Mainland China, Malaysia, Indonesia, Thailand, Vietnam, India, and many other countries. The relatively good ranking of Singapore in *Trends in Mathematics and Science Study (TIMSS)* and *Programme for International Student Assessment (PISA)* in recent years may result in more foreign students studying in Singapore.

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# 14 School science in New Zealand

## Support for curriculum reform and implementation

*Cathy Bunting and Alister Jones*

### **Introduction**

Aotearoa New Zealand is an island country in the South West Pacific Ocean, and because of its geographic isolation was one of the last landmasses to be populated by humans. Today, New Zealand has a resident population of around 4.5 million, of which 74% identify as Pākehā (of European descent), 15% as Māori (indigenous people), 12% as Asian and 7% as Pasifika, or Pacific peoples (Statistics NZ, 2014). Education is compulsory for all children aged between six and 16 years, although most children begin school on or just after their fifth birthday. Primary schools cater for children from the age of five years to the end of their eighth year of schooling. Children in Years 7 and 8 (12–13 year olds) may either be in a separate intermediate school or part of a full primary, secondary or composite (Years 1–13) school. Secondary schools usually provide for students from Year 9 until the end of Year 13. Kura kaupapa Māori are Māori language immersion schools where the philosophy and practice reflect Māori cultural values, although in 2014 less than 3% of the total cohort of students were enrolled in these schools (Statistics New Zealand, n.d.). There is a long history of a national curriculum, although schools are self-governing and responsible for implementing their own teaching and learning programmes. As a result of our unique colonising history, education policy specifically also emphasises the importance of Māori succeeding as Māori.

### **The development of a national curriculum and self-managing schools**

The Education Act 1877 established New Zealand's first secular, free national system of education, making it compulsory for all 7–13 year olds to attend school. The Education Act 1914 required secondary schools to offer free education to all who passed a proficiency examination. As a British colony, the early curriculum was influenced by curriculum development in England.<sup>1</sup> Teaching methods were based on behaviourist views of learning, and compulsory subjects included English, Arithmetic, Drawing, Singing, Physical Instruction, Moral Instruction, Nature Study and Health. As such, schools were balancing cultural education

with education for vocational purposes – a tension that continues today, and that impacts on the types of science education that are offered in contemporary New Zealand schools.

In 1944 – only 70 years ago – free schooling was established for all secondary students. New regulations made a core of general subjects compulsory for all students, although streaming into academic, commercial and domestic or trades pathways meant that students received different versions of the core curriculum (Nolan, 2009). Incorporation of New Zealand elements has been prioritised in the curriculum since very early on, with the *School Journal* (published since 1907) presenting stories relevant to a New Zealand way of life.

The 1970s and 1980s saw growing dissatisfaction with education by parents, schools, communities and the government. In particular, there were concerns that the school system had been too slow to respond to changes in the New Zealand economy, which was moving from being an outpost British farm to an independent trading nation operating in most parts of the world. Calls were made for the curriculum to be responsive to the country's needs for people highly skilled in science and technology, and with the languages and cultural sensitivity needed to maintain international economic competitiveness. In addition, the curriculum was seen as not being relevant for many students and not maximising learning for many Māori and Pacific Island students, and girls. By the 1980s, the direction and purpose of the school curriculum was a topic of public debate and a target by lobbyists for change. Recommendations were for a national curriculum that provided for a broad and general education. A Draft National Curriculum Statement (Department of Education, 1988) identified the following curriculum areas: culture and heritage; language; creative and aesthetic development; mathematics; practical abilities; living in society; science, technology and the environment; and health and well-being. A summary of support for and critiques of this draft can be found elsewhere (e.g., Codd, 1993).

A further shift for curriculum implementation came with the 'Tomorrow's Schools' reforms legislated in the Education Act (1989), when schools became autonomous, self-managing entities with responsibility for their teaching programmes and finances. The Board of Trustees, which includes parental, community and school representation, is responsible for setting the direction of the school, within the parameters of regulation, and is accountable for the school's performance to the Education Review Office (an independent audit agency) and to the Ministry of Education.

## **Science in the school curriculum**

In the early 1990s, the Ministerial Task Group Reviewing Science and Technology Education, appointed jointly by the minister of education and the minister of research, science, and technology (MoRST), was tasked with assessing the effectiveness of science and technology education in delivering the skills and knowledge required by society and the work place. Its report, *Charting the Course* (MoRST, 1992), gave voice to the views of business people and highlighted



that science education had placed too much emphasis on the transmission of content knowledge, neglecting skills such as communication, problem solving and cooperation. The report also recommended that a general science curriculum suitable for all students be developed for Years 1–13, with specialist science courses restricted to Years 12 and beyond. This theme continues to be promoted in government-commissioned reports (Bull, Gilbert, Barwick, Hipkins, & Baker, 2010), although it is up to schools, as self-governing entities, to determine how to implement this approach in their context.

The 1993 New Zealand Curriculum Framework (Ministry of Education, 1993a) separated science and technology into distinct learning areas. Schools were required to ensure all students undertook study in both these ‘subjects’, in Years 1–10, and learning outcomes for science were grouped into six integrated learning strands. Four strands (making sense of the living world, making sense of the material world, making sense of the physical world, and making sense of planet Earth and beyond) provided the broad learning context through which the other two integrating strands (Developing scientific skills and attitudes, and making sense of the nature of science and its relationship to technology) were to be developed (Ministry of Education, 1993b). Māori versions of both the *New Zealand Curriculum Framework* and *Science in the New Zealand Curriculum* were also written (*Te Marautanga o Aotearoa*, Ministry of Education, 2008).

In 2000, the Ministry of Education initiated the Curriculum Stocktake project to inform the ongoing development of the national curriculum. Within this broader project, the National School Sampling Study sought feedback about the effectiveness of the curriculum in practice, surveying approximately 10% of the nation’s teaching workforce. The report detailing teachers’ experiences using the science curriculum document highlighted concerns among many teachers about the ‘over-crowded’ curriculum, and the importance of facilities and resources to support science teaching (McGee et al., 2003). The main suggestions for change to the curriculum were the provision of more detail around the ‘big ideas’ as a support for teacher planning, and reducing overall content to allow time for higher order thinking and problem solving.

Early in the new century, an integrated curriculum framework, the *New Zealand Curriculum* (Ministry of Education, 2007) began to be developed. The goals of this work included refining and clarifying learning outcomes; adding a focus on effective teaching; strengthening school ownership of the curriculum; and strengthening partnerships with parents and communities (Cubitt, 2006). Teaching is positioned as a professional process of ongoing reflection and inquiry, and schools are encouraged to explore how digital technologies can open up new ways of learning. The document assumes school-specific curriculum development, in line with New Zealand’s self-governing schools policy.

In the learning area of science, the New Zealand Curriculum states that “students explore how both the natural and physical world and science itself work so that they can participate as critical, informed, and responsible citizens in a society in which science plays a significant role” (Ministry of Education, 2007, p. 17). In other words, the use of science for citizenship is highlighted, and both knowledge

and nature of science (NOS) are seen as essential inputs for achieving this outcome. With respect to the learning objectives, these were deliberately reduced across all learning areas. For science, the NOS was identified as the overarching, unifying strand. It consists of Understanding about Science, Investigating in Science, Communicating in Science, and Participating and Contributing. The outcomes of this strand are pursued through the contexts of the Living World, Planet Earth and Beyond, Physical World, and Material World. More recently, the Ministry of Education has identified five science capabilities that contribute to a functional knowledge of science: gather and interpret data, use evidence, critique evidence, interpret representations, and engage with science (Hipkins, 2014). Examples demonstrate how existing resources can be used to support students' development of different science capabilities across the levels of the curriculum.

Overall, the New Zealand Curriculum and supporting resources encourage innovative, engaging approaches to science education that emphasise both scientific concepts and the process of science. However, the impact of high-stakes assessment continues to drive practice in a number of ways.

### **National assessment and achievement in science**

The national secondary school qualification, the National Certificate in Educational Achievement (NCEA), is a standards-based qualification that was introduced in 2002 and represented. Each achievement standard is worth a pre-determined number of credits, and work is judged as being not achieved (N), achieved (A), achieved with merit (M), or achieved with excellence (E). Some standards are constructed by teachers and internally assessed, with moderation monitored by the New Zealand Qualifications Authority. Other standards are externally assessed and take the form of conventional examinations.

Science has an extensive range of achievement standards that can be used to design and assess senior courses, but the fragmentation of the subject into discrete internal and/or external standards can be both a strength and a weakness (Jones & Bunting, 2013) – while the range of standards allows for flexibility in course design and greater customisation of individual learning programmes, students are able to choose not to be assessed in parts of a course that they do not like, or think they will do poorly in. High-stakes assessment also influences the curriculum experienced by students. For example, students need only experience a very narrow view of scientific investigation in order to successfully achieve the achievement standard, 'Carry out a practical investigation with direction' (Hume & Coll, 2010; Moeed, 2015). In addition, University Entrance requirements can impinge on the types of science courses schools choose to offer. This is tragically ironic, given that university science increasingly reflects the multi- and inter-disciplinary nature of modern science endeavours – and yet university administration continues to require a large number of credits in discrete, traditional bundles like 'chemistry' and 'biology'.

In terms of choosing science at senior secondary school, a 2005/2006 study investigating declining enrolments in science at senior secondary and tertiary

levels in New Zealand, called *Staying in Science* (Hipkins & Bolstad, 2005; Hipkins, Roberts, Bolstad, & Ferral, 2006), found that two important factors influencing students' choices to continue with science at secondary and tertiary level were students' experiences of school science, and their knowledge and awareness of the range of study and career options that involve science. Importantly, an intention to continue studying sciences appears to begin, at least for some students, much earlier than senior secondary school. Ability in mathematics was also important for students with a serious intention to continue in the sciences, raising questions about the influence of early mathematical success in later engagement in science education, whether for general citizenship or for a science-related career.

At the primary level, science tends to be taught by generalist classroom teachers except at Years 7/8, where there may be specialist science teachers. A 2012 investigation by the government's Education Review Office (ERO, 2012) found that effective practice in science teaching and learning was evident in less than a third of the 100 schools that were evaluated, with wide variability in practices. Importantly, leadership was identified as a significant contributor to the quality of science teaching and learning, the school principal actively promoting science in schools where effective practice was identified. These schools also had lead teachers with a strong interest in, and a passion for, science, and worked proactively to foster staff knowledge and confidence in teaching science. In less effective schools, science had low priority, science programmes lacked coherence and continuity, teachers had little useful data on student achievement in science, there was a lack of understanding of the science curriculum requirements and what constitutes effective science teaching, teachers were often not confident or well prepared for teaching science, and there were limited ongoing professional development (PD) opportunities. Some of this lack of emphasis on science is perhaps not surprising given the pressure on schools to report on student achievement against National Standards in literacy and numeracy, introduced to New Zealand primary and intermediate schools in 2009 (Thrupp & White, 2013). However, the evidence is worrying. Also worrying is the ongoing disparity in achievement between students from different ethnic groups (McKinley, Gan, Bunting, & Jones, 2015).

These issues are evident in national monitoring of students' understanding about and attitudes towards science, particularly at the end of primary/intermediate schooling. This monitoring occurs through the National Monitoring Study of Student Achievement, operating since 2012, and its predecessor, the National Education Monitoring Programme (NEMP, 1995–2010). Working on a four-yearly cycle, snapshots of Year 4 (9–10 year old) and Year 8 (12–13 year old) student achievement are provided across the curriculum in order to identify factors associated with achievement and to monitor changes over time. Assessment tools include paper-and-pencil tests assessing students' science content knowledge, an attitude and self-efficacy questionnaire, and triangulating interviews. The most recent results for science, from 2012, indicated that while the average results for Year 4 students aligned with the expected level

described in the *New Zealand Curriculum*, the average Year 8 results did not reach the expected curriculum level. In addition, average scores were lower for Māori and Pasifika students than other ethnic groups, and disparity was linked to socioeconomic status. Year 4 students were more positive about science than Year 8 students, and there was a correlation between attitudes to science and science achievement.

New Zealand's participation in the TIMSS shows a wide range of achievement compared with high-performing countries and a lower proportion of high performers and higher proportion of low performers than high-performing countries (Caygill, Hanlar, & Singh, 2016; Caygill, Singh, & Hanlar, 2016). TIMSS also provides evidence of links between New Zealand students' science achievement and socioeconomic status, and between science achievement and primary students' positive parental attitudes towards science and mathematics. At primary level, only 15% of the participating NZ students had teachers who had specialised in science (compared with the international average of 38%), and about half the teachers did not feel very well prepared to teach science topics. Fewer primary teachers in NZ had engaged in PD in science when compared with their international colleagues. Together, these findings raise concerns about the equity in learning outcomes for all students, perhaps particularly at primary level – when students can form lasting impressions of science (Hipkins & Bolstad, 2005).

### **Initiatives to raise science engagement and achievement**

Over recent decades, waves of initiatives to raise student engagement and achievement in science can be identified – many corresponding to declining performance (both real and relative to other economies) in international assessments (Jones & Bunting, 2013; McKinley et al., 2015). For example, a Mathematics and Science Taskforce was established in 1997 in response to New Zealand's disappointing TIMSS rankings (Baker & Jones, 2005). One practical outcome was the production of several book series designed specifically to support the teaching and learning of science in primary schools. Second, a literature review (Jones & Baker, 2005) commissioned by the Ministry of Education identified a range of features likely to positively influence the success of all students, but particularly those traditionally over-represented in the lower achieving cohorts on TIMSS – features that still remain relevant today. First, effective teachers use pedagogies that raise their own and the students' awareness of the range of ideas about a phenomenon, situation or learning process, and these ideas are taken into account when planning and implementing learning experiences. In other words, there is a recognition of prior knowledge, as well as the 'funds of knowledge' (González, Moll, & Amanti, 2005) that students bring into the classroom. Second, students are aware of the purposes for the learning – a point that also brings to attention the importance of teachers having a clearly articulated view of the purposes of the science learning. As argued more recently by Hipkins (2012), "How [teachers of science] understand their work is framed first and

foremost by the purposes for which they think they are teaching science, and the sorts of learning outcomes they see as having value for learners” (p. 14). Third, effective learning experiences help students to build a wide range of rich experiences of the world around them, and teachers help students to build bridges between their own life worlds and the cultural world(s) of science. Here, attention is drawn to the importance of learning being authentic and meaningful, and linking to the processes and purposes of science. Fourth, students frequently engage in purposeful dialogue with the teacher and/or with groups of their peers. Conversations are scaffolded by the teacher, with explicit modelling of the type of discourse that is appropriate and of the type of outcome/ product to be achieved. This highlights the social nature of learning, and also enables teachers to engage in strong formative interaction to help students as they learn. Fifth, effective pedagogies emphasise depth rather than breadth, resulting in less ‘content’ being more fully explored, investigated, and understood. One approach here is to focus learning around an aspect of the NOS, and to use different contexts to explore this. While such an approach is signalled by the framing of the *New Zealand Curriculum’s* science learning area, it turns a more conventional teaching approach (where content is prioritised and learning about the NOS is opportunistically woven in, see Hipkins, 2012) on its head. Finally, teachers routinely use basic literacy strategies to help students to decode science text, and use a variety of pedagogies that not only require students to read and/or write, but that actively engage students’ own thinking. Such a literacy focus not only aligns with schools’ current focus on National Standards in literacy, highlighting the contribution that other ‘subject’ learning makes to literacy goals, but the NOS component, Communicating in Science, articulated in the *New Zealand Curriculum*, specifically draws attention to the importance of students being able to use and interpret scientific symbols, conventions, vocabulary and texts as part of their broader science learning. Issues around pre-service teacher education and ongoing access to professional learning were also raised.

More than a decade later, substantive shifts are difficult to identify. Perhaps there is potential for change with the recent re-focusing on science education in New Zealand, and science communication more generally, driven by political rhetoric around the importance of science (and STEM) for economic and social benefit (Gluckman, 2011). For example, the report *Engaging Young New Zealanders with Science: Priorities for Action in School Science Education* (Bay, Meylan, Leaman, Gibbs, & Beedle, 2011) called for:

- communities (including families, educators, scientists, and wider society) to explore and develop a shared understanding of the purpose of science education at different stages of [student] development;
- development of effective collaboration and interaction between science and science education to enable schools to offer science education that meets the needs of 21st-century learners, including enabling contemporary contexts to be used in teaching;

- development of strategies to better integrate science into teaching and learning programmes in primary schools, including addressing pre-service and in-service teacher needs;
- development of innovative courses to provide for the diversity of goals in secondary school science and variant assessment pathways; and
- support for enhancing Māori and Pasifika engagement and achievement in science.

Some of these objectives were picked up by government in *A Nation of Curious Minds – he whenua hihiri i te mahara: A National Strategic Plan for Science in Society* (New Zealand Government, 2014), jointly produced by the Ministry of Business, Innovation and Employment (MBIE), the MOE and the Office of the Prime Minister’s Chief Science Advisor. However, important discussions about the purposes of science education in a changing landscape seem to have been underplayed (Stewart & Bunting, 2015). In addition, funding has largely privileged initiatives involving expertise and resources from outside of schools to contribute to school programmes and/or the up-skilling of science teachers. While not without merits, such an approach runs the risk of ignoring the rich resources that exist within and between schools in terms of science teacher expertise, and the benefits that could be gained from maximising and building critical mass for sustained change.

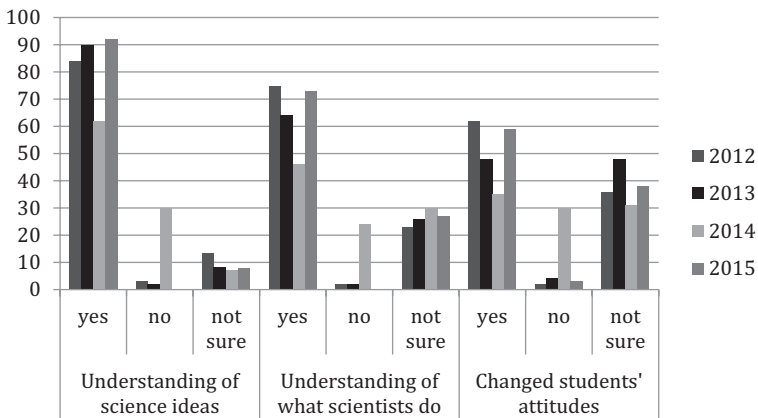
### *The Science Learning Hub*

The Science Learning Hub ([sciencelearn.org.nz](http://sciencelearn.org.nz)) is a long-term initiative launched in 2007 and funded by the MBIE and its predecessors, rather than the Ministry of Education. A comprehensive online resource, multimedia content features stories of contemporary scientific research and development supported with extensive teaching and learning activities – thus providing teachers with examples of New Zealand research and development to contextualise school science learning and make it more relevant. Content is developed with input from scientists, science teachers, science education researchers, and multimedia experts, and the range of content currently available reflects not only government investment in the project but also the enormous and generous contributions of a large number of scientists and science organisations across New Zealand. The Hub work programme includes ongoing content development, online PD, and social media activity to promote the Hub and support use of the resources among teachers, scientists, and the wider community.

The initial brief of the Science Learning Hub was “to link Year 9 to 13 science students and their teachers to research being done in New Zealand”. The objectives were that students whose teachers used the Science Learning Hub would (a) show increasing levels of interest in studying science, and (b) would increasingly believe that science is relevant to their everyday lives. In other words, the purpose was to enhance both science education for future careers, as well as science education for more general citizenship. In 2008, the work was expanded to

include Years 5 to 8, and more recently, content has been developed specifically for junior and middle primary teachers. The contract for the Science Learning Hub also now falls under the government's 'Science in Society' plan referred to earlier. As such, the goals of the Hub are to contribute to the following outcomes under the Science in Society plan: greater teacher confidence in teaching science; teachers having improved access to the resources they need to teach science subjects; and a greater proportion of New Zealanders across all sectors of society are engaged with, and value, science and technology.

These are lofty goals, since the use of any resource – no matter how comprehensive or relevant – depends on how it is adopted and adapted within the wider science education system and context, as well as by individual teachers and schools. However, an extensive programme of survey and classroom-based research has highlighted that teachers who use the Hub particularly value the New Zealand examples, and the teacher resources and student activities. In addition, teachers who use the Hub in their classes report that their students have a better understanding of science and of what scientists do, and that they have more positive attitudes towards science (see Figure 14.1). Perhaps not surprisingly, teachers who receive PD related to using the Hub are more likely to visit it more frequently, use it for more purposes, and use a wider range of Hub resources. In addition, those who have received PD are more likely to report changes in their teaching since using the Hub, and to find it useful. This highlights the importance of ongoing support for PD opportunities, not only to



*Figure 14.1* Percentage of NZ educationalists (2015) and NZ teachers (2014, 2013, 2012) who used the SLH in the class reported changes in students understanding of science ideas, understanding of what scientists do, and attitudes towards science (2012, n = 130; 2013, n = 132; 2014, n = 272; and 2015, n = 37). The survey was available as a link from the Science Learning Hub for a period of approximately six weeks, and so only those visiting the website were surveyed.

raise awareness of the Hub and its many resources among teachers but also to create opportunities for them to share with each other how they are using the Hub resources.

In the ten years since the Science Learning Hub's inception, vast changes have occurred in web-based technologies. Science has also continued to change, with new knowledge and techniques, and the need for the Hub to continue to reflect ongoing scientific developments is paramount. In addition, there are changing expectations regarding how New Zealand scientists engage with the wider community (Salmon & Priestley, 2015) and an increasing range of web-based outlets for the dissemination and discussion of new scientific findings. Within this changing landscape, the Hub faces a range of different tensions. The first is related to the increasing number of channels through which scientists and science organisations can communicate. This points to the need for the Hub to retain its value through (a) being able to link isolated but related resources from a variety of sources together, and make them accessible, (b) making science content pedagogically meaningful, (c) being responsive in how we connect with both the science and education sectors, and (d) continuing to raise awareness of the value-add that can be provided to both science and education. A second tension relates to defining the audience, with evidence that the Hubs are regularly visited not only by teachers but also by students, parents, and the wider community. These diverse audiences have different needs, and decisions need to regularly be made about which content to prioritise in order to cater for the range of needs and interests. A related tension concerns the funding for the project, which continues to come from Vote Science rather than Vote Education, and the agenda of the Science in Society Plan to increase the proportion of New Zealanders engaging with, and valuing, science and technology. The concern here is that, educationally, 'valuing science and technology' needs to be approached from a critical perspective, rather than a blind acceptance that all science and technology is necessarily good – and such a critical stance needs to be imbued across the Science Learning Hub, in spite of its funding source, and because of it.

## **Concluding thoughts**

New Zealand is a small democracy with a bicultural heritage and a robust infrastructure. While there is a long history of a national curriculum, schools are self-governing and required to make their own decisions about how to implement their teaching and learning programmes. In particular, the 2007 New Zealand Curriculum emphasises community engagement so that “the curriculum has meaning for students, connects with their wider lives, and engages the support of their families, *whānau* [the Māori word for extended family], and communities” (Ministry of Education, 2007, p. 9). Our unique colonising history places emphasis on Māori achieving as Māori. While there are a large number of initiatives to support this, there is still much to be done and Māori education and success remains a government priority.



Two substantive revisions to the curriculum since the 1990s have successively raised the profile of the NOS within the science curriculum, although this has had varying impacts on students' experiences of school science. In addition, there have been major shifts in high-stakes assessment, including the introduction of the standards-based NCEA at senior secondary level, and National Standards in literacy and numeracy at primary level. At primary level, this may have impacted on the amount of time committed to science teaching and learning. At secondary level, NCEA tends to drive the curriculum that is experienced by both senior and junior secondary students. In addition, there is little evidence of innovative packaging of achievement standards (McKinley et al., 2015).

National and international assessments indicate a wide range of achievement, with ongoing disparity between students of different ethnic groups, average scores for Māori and Pasifika students being lower than those for Pākehā and Asian students. Average results for Year 4 students align with expectations of the national curriculum, but at Year 8 they fall below expectations. Students who choose science options at senior secondary level, and into tertiary study, tend to be influenced by students' experiences of school science, and their knowledge and awareness of the range of study and career options that involve science. Choices also appear to often be made much earlier than senior secondary school.

Efforts to raise public engagement with science, including school students' engagement and achievement in science, have recently been brought together in the government's 2014 Strategic Plan for Science in Society. This plan aims to "encourage and enable better engagement with science and technology in all sectors of New Zealand" (New Zealand Government, 2014, p. 9) and is comprised of three actions: enhancing the role of education; public engaging with science and technology; and the science sector engaging with the public. Within the first action, the Science Learning Hub offers a vehicle for new science research and developments to be made accessible to school teachers, students and the wider community. However, it is the connections with pedagogical approaches where the value-add becomes significant, and an ongoing programme of work is required to ensure that the Hub remains up to date, responsive, and relevant to the needs of both the education and science communities. More broadly, robust discussion is needed about the purposes of science education at different levels of schooling, coupled with professional learning opportunities for teachers to explore what different emphases mean for students' experiences of science learning in and out of school.

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The early parts of this chapter draw on work by Jones and Cowie (2010).

## Note

1 In 1907, New Zealand became an independent Dominion. Full independence was obtained in 1947, although in practice Britain had ceased to play any real role in government much earlier than this.

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