Chapter 2
Design and Implementation of the National Primary Science Curriculum: A Partnership Approach in Singapore

Tan-Ying Chin and Chew-Leng Poon

Abstract Singapore has a national science curriculum that spans from the primary levels, where it is mandatory, to the pre-university levels where science subjects are electives. The science curriculum undergoes a 6-year review cycle, with an intermediate third-year review to ensure currency of the curriculum. In this chapter, we present a partnership framework for curriculum design and implementation that fosters close collaboration among curriculum developers, school leaders, science educators and practitioners. Exploring this partnership specifically through the development of the primary science curriculum, we describe the interactions between partners, the curriculum design and implementation processes and the features that support this partnership approach. We discuss the challenge of partnership in teacher professional development that was identified by our partners as an area for improvement in this framework. This narrative has included the voices of our partners to bring deeper insights and perspectives into both policies and practice at the various stages of curriculum design and implementation. We hope that these insights and discussions would be useful to educators and curriculum developers who are involved in or exploring different approaches in curriculum design and the implementation process.

Keywords Science education • Primary science • Curriculum design • Curriculum implementation • Curriculum, pedagogy and assessment • Science curriculum framework • Science inquiry • Curriculum partnership framework • Teacher professional development • Teacher professional learning

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Introduction

Curriculum can be viewed as 'an interrelated set of plans and experiences that a student undertakes under the guidance of the school' (Marsh & Willis, 2003, p. 13). Though stated simply, we like Marsh and Willis' definition of the curriculum as it encompasses the concepts of the planned, enacted and hidden curriculum that are relevant to the Singapore context. Singapore has a national curriculum and therefore a large part of the planned curriculum is very explicit to teachers, parents and even students. Marsh and Willis' inclusion of 'experiences' would embody the curriculum that is enacted in the classrooms, which may differ from the planned curriculum as teachers interpret the planned curriculum through their own beliefs and experiences and as they interact with students and with the curriculum materials. The culture of the school and classroom (e.g., whether teachers encourage or discourage students to speak their mind in class) and the interactions among teachers, students and the physical environment are all part of the hidden curriculum that shapes the 'experiences' of the students. What a student experiences in the classroom is often a result of a complex web of interactions and transactions between the actors (e.g., teachers and students) in the classroom, the physical environment, the materials (e.g., textbooks) and the values and social norms adopted by the different actors. Given this complexity, it is not surprising that the curriculum, or what goes into the curriculum, has been a subject of much debate and deliberations among educators through the years (e.g., Bruner, 1960; Dewey, 1916; Eisner, 1994; Tyler, 1949). The science curriculum is of no exception. What is to be taught in science, how to teach it, how students learn it and how much time should be allocated to it are some constant issues of interest and even tussles (e.g., Driver & Oldham, 1986; Hargreaves, 1994; Marsh, 2009; Schwab, 1962). Who makes these curriculum decisions and how is the curriculum negotiated and deliberated (McCutcheon, 1995) and at which points are also important areas of research that have an impact on what and how students learn.

Curriculum research is indeed a very broad field. Our interest in this chapter is focused specifically on the partnership roles of stakeholders in the various stages of the curricular design and implementation process. We regard any stakeholders who work alongside each other in the curriculum design and implementation process as 'partners'. Partnership refers to the various dynamic forms of working together. This is an important area of study particularly for countries or education systems that adopt a national curriculum, such as Singapore, as the entire body of curricular stakeholders (curricula developers, curricula resource developers, science educators, examinations board and teachers) has to understand the philosophy, intent and details of the curriculum to see through the successful implementation of the curriculum. Research in the field of curricula adoption and fidelity of implementation has shown that the processes of curricula implementation could impact learning (e.g., Adey, 2004; Lee & Chue, 2013). Knowledge on the approaches to engage teachers in curricula implementation is therefore critical.

Recent research on teachers' professional development, learning and change processes have also demonstrated the important roles teachers play, not just in curriculum implementation but also in curriculum design (Clarke & Hollingsworth, 2002; Darling-Hammond & Bransford, 2005). Teachers are viewed as active shapers of curriculum change to meet local school needs and to fill gaps in the design of the curriculum (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). Hence, many recent studies focused on fostering collaboration between researchers and schools to encourage teacher ownership of curricular innovations (McMillan-Culp & Honey, 2000). This trend of devolving greater responsibility and ownership to teachers (e.g., in selection of content and methods of teaching) was also observed in an OECD (Organisation for Economic Co-operation and Development) project involving 13 participating countries (Atkin & Black, 2003). The teachers in the participating countries played different roles in curricular design and implementation. For instance, teachers in Germany initiated and developed the integrated science curriculum in consultation with academics from universities. Teachers in Japan trialled and influenced changes to the new elementary school curriculum in 'Environmental and Life Sciences' developed by their Ministry of Education. While these recent studies provided insights into how teachers were involved in developing and customising the curriculum and curricular materials, we felt that inadequate attention has been paid to understanding the dynamics of the partnership between stakeholders (e.g., curriculum planners, researchers and school practitioners) in the entire curriculum design and implementation processes.

This chapter, therefore, is an attempt to describe and reflect on the roles and dynamic relationships between these different stakeholders, explored specifically through the development of the Singapore primary science curriculum. We describe a partnership framework for curricular development and implementation that we used. Further, we elaborate on features of the framework and the challenges and opportunities afforded through the framework to initiate conversations among curriculum developers and school practitioners that could help improve the processes of curriculum design and implementation.

Method of Inquiry to Understand Partnership in Curriculum Design and Implementation

To better understand the curriculum partnership, we gathered information on the process of curriculum design and implementation across the various curriculum cycles since the 1960s. We examined curricular documents and other published materials about the Singapore primary science curriculum. Besides, we also invited 17 partners involved in the various cycles and stages of curriculum design and implementation to respond to a questionnaire. These partners include curriculum developers, school leaders, master teachers,[1] heads of science departments and partners from various science institutions. The questionnaire fielded open-ended questions such as:

1. Describe the role you played in the curriculum review. Describe how this contributed to the development of the curriculum.
2. In your opinion, what guided this primary science curriculum review/ implementation?
3. What is/are the focus in this primary science curriculum review/ implementation?
4. What process has helped ensure that the primary science curriculum stays connected and relevant to that of secondary schools and postsecondary education?
5. What do you think helped the curriculum planners, school leaders and teachers as well as the science community decide what is current and relevant to science and the Singapore society in the twenty-first century?
6. What is/are the challenge(s) you faced in implementing this primary science curriculum and how was it overcome?

Besides data from the questionnaire survey, we also conducted one focus group discussion with five respondents to gather deeper insights on the following key questions in the questionnaire:

1. What have been useful in guiding curriculum design and implementation over the curriculum cycles?
2. How have the curriculum design processes (e.g., scanning literature and practices, gathering feedback and consultations) (1) helped to ensure that the science curriculum in primary schools stay relevant and coherent with the curricula in secondary and post-secondary education and (2) helped the curriculum planners decide on what is current and relevant to science and the Singapore society in the twenty-first century?
3. What are the challenges in curriculum design and implementation and what minimises gaps between the intended, implemented and attained curricula?
4. How are partnerships in curriculum design and implementation important in encouraging greater curriculum ownership and higher levels of fidelity in curriculum implementation (encouraging teachers to take greater ownership as designers and facilitators of student learning as inquiry)? Why?

The interview session was audiotaped and later transcribed verbatim. Responses to the questionnaire and the interview transcript were systematically examined to fill in gaps in our knowledge about the different roles of the stakeholders in the

[1] School leaders, including the Principals, Vice Principals and heads of the science department provide instructional leadership for science teaching and learning in the schools. Master teachers are identified expert teachers who support teachers at the national level. They foster pedagogical leadership focused on teacher collaboration in learning communities within and beyond schools in professional networks. These networks serve to strengthen the culture of teaching excellence and raise the standards of practice in the classroom and across Singapore's education system.

curriculum design and implementation process. We also noted elements of partnership in the respondents' description of the curriculum design process, the partnerships which were enacted at each stage and the challenges and opportunities that arose from the partnership.

In writing this chapter, we drew on much of our institutional knowledge to describe the curriculum design processes, but acknowledge that the lens through which we narrate the curriculum partnership are limited by our own experiences and beliefs shaped by about 20 years (each) of involvement in science education. To augment this, we have therefore included our partners' voices liberally so that their perspectives and views will add to the richness of this narrative. This, in a way, is also consistent with the central philosophy of the chapter – that curriculum design is very much a concerted effort of the different stakeholders.

We begin the chapter with an overview of science education in Singapore and the evolving emphases in the primary science curriculum to provide the background and context to understand the curriculum design and implementation processes. This sets the stage for us to launch into the discussion on our curriculum partnership framework.

Overview of Science Education in Singapore

Structure of Science Education in Singapore

Singapore's national science curriculum spans from the primary levels, where it is mandatory, to the pre-university levels where science subjects are electives. Figure 2.1 shows an overview of the broad structure of science subjects offered across the educational levels.[2]

The responsibility of developing the curriculum for each of these science subjects lies with the Curriculum Planning and Development Division (CPDD) at the Singapore Ministry of Education (MOE). The division reviews the science curriculum on a 6-year cycle, with an intermediate third-year review to ensure currency of the curriculum. A science curriculum framework (Ministry of Education, Singapore [MOE], 2008), as shown in Fig. 2.2, guides curriculum design and ensures that a common set of philosophy threads through all of the science curricula across the primary, secondary and pre-university levels. The framework was conceptualised

[2] At the primary and lower secondary levels, students are offered general science. At the upper secondary levels, students can be offered pure science subjects or combined science subjects (comprising a combination of two science disciplines). At the pre-university levels, students can be offered science subjects at H1, H2 or H3 levels (with H3 level subject of the highest content and demand).

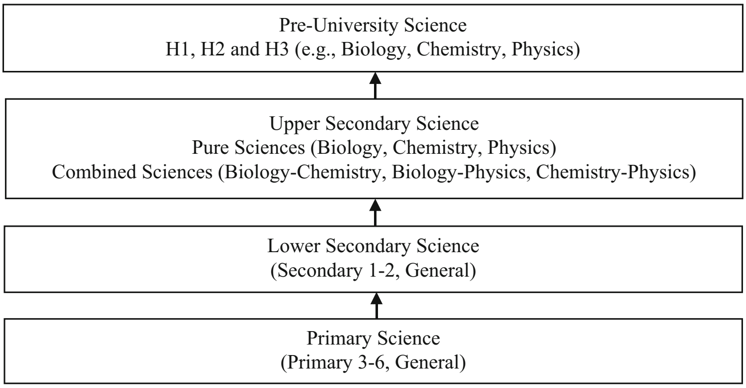

Fig. 2.1 An overview of the science subjects offered across educational levels in Singapore

from theories and practice of inquiry science, guided by a set of desired outcomes of education and vision of science education in Singapore. Inquiry is central to the curriculum framework and developed through the three integral domains of knowledge, skills and ethics. The meaningful pursuit of scientific inquiry is set in the contexts of science in daily life, science in society and science in the environment.

Evolution of the Emphases of the Primary Science Curriculum

As documented in Chap. 1 'Five decades of science education in Singapore', science first became a part of the formal primary school curriculum in Singapore in 1959. The primary science curriculum then and through the 1960s focused mainly on the teaching of plants and the environment, although much broader aims were stated in the curriculum, namely, '(a) to create an interest in nature and its working; (b) to encourage the natural curiosity of children and to inculcate a spirit of inquiry; and (c) to train the children to observe, to experiment and to seek further knowledge' (Yeow, 1982, p. 160). Although 'inquiry' and 'experimentation' were mentioned in the aims of the curriculum, Yeow inferred a more book-centric delivery of the curriculum.

In the 1970s, the primary science curriculum was broadened beyond the teaching of plants and the environment. Physical science topics were included to provide a more balanced learning experience and also a foundation in physical science concepts at the secondary level. This curriculum effort was fronted by the Ministry of Education – Science Teachers Association of Singapore (MESTAS), which comprised teachers from the Science Curriculum Branch of the Ministry of Education (MOE) and the Science Teachers Association of Singapore (STAS).

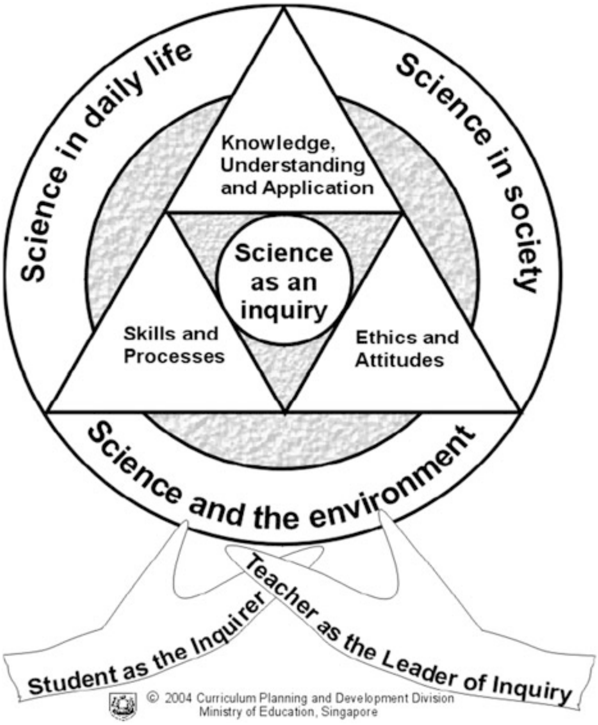

Fig. 2.2 Science curriculum framework in Singapore (Used with permission from the Ministry of Education)

In the 1980s, the primary science curriculum was further revised to include process skills. This curriculum revision was undertaken by a team of teachers and curriculum officers who made up the Primary Science Project (PSP) Team at the Curriculum Development Institute of Singapore (CDIS). A member of the PSP team who was involved in the review and implementation of the primary science curriculum explained that the decision to include process skills was partly inspired by 'discovery-centred approaches' observed in study trips to the United States. Singham (1987) described this first set of locally produced primary science curriculum materials (implemented from 1982) as giving more emphasis to the teaching and learning of science process skills such as observation skills, collection and interpretation of data and classification and measurement skills. The teaching and learning of science process skills continued to be emphasised in the 1990s curriculum.

At the turn of this century, the curriculum review committee initiated a thematic approach to organising the 2001 primary science curriculum (Ministry of Education, Singapore [MOE], 2001). Five integrated themes were developed – Diversity, Cycle, System, Interaction and Energy. The distinction in this curriculum was the effort to communicate a more coherent and integrated understanding of science that bridged the life science–physical science divide. The objective of this thematic organisation was to help students appreciate the links between concepts in different topics, thus progressing towards developing 'big ideas' in science (Harlen, 2004; Millar & Osborne, 1998). For example, in the theme of 'Diversity', a 'big idea' developed in the curriculum was the appreciation of the great variety of both living things and materials in the world and the importance of sustaining the diversity. Classification by observing similar and different characteristics and properties was a tool students learn as a way to make sense of the diversity and interaction between different groups. Although the thematic approach was not widely used internationally at that time, members of the curriculum review committee and teachers consulted were convinced that the themes will lead to better development of overarching concepts or unifying principles in science. A member of the curriculum review committee reflected on the motivation for organising the curriculum through themes:

> Thematic approach brings a more holistic understanding of the science concepts. I believe the themes do help (students) appreciate the concepts of diversity and organisation, cause and effect, systems, structures and functions, models and change. (Angie, survey, 21 Jul 2012)

This thematic organisation of the primary science (and lower secondary science) curriculum was retained in the 2008 curriculum. Beyond the thematic organisation, the 2008 primary science curriculum also introduced the curriculum 'white space', in line with the nationwide initiative to 'Teach Less, Learn More'. This involved reducing the number of learning outcomes in the curriculum (therefore having 'less to teach'), thus creating space and flexibility for teachers to better customise the curriculum to meet the needs of their students as well as to use more inquiry-based teaching and learning approaches (with the aim of students 'learning more').

The 2008 curriculum also gave explicit emphasis on inquiry in the teaching of science. This emphasis on inquiry took place against a backdrop of a number of key developments, both within and outside Singapore. One of these developments was the publication of the US *National Science Education Standards* by the National Research Council (NRC) in 1996. The inquiry-centric standards (National Research Council [NRC], 2000) generated a fair amount of discussion and interest among curriculum designers, educators and the science community in and beyond the USA. While students in Singapore have been doing fairly well in international benchmarking studies, such as the Trends in International Mathematics and Science study (TIMSS, e.g., Bybee & Kennedy, 2005), research into classroom practices surfaced areas for improvement. According to a study by Luke, Freebody, Lau, and Gopinathan (2005), Singapore's science classrooms displayed a largely 'didactic, traditional and rote reproductive character of pedagogy' (p. 11), which falls short of the MOE's call for a more student-centric active learning environment. Teaching and learning science through inquiry was seen as a way to help teachers better engage students in the learning of science.

Beyond the classrooms, Singapore was then gearing to meet the social, technological and economic challenges of the twenty-first century. Policymakers saw science education playing an important role in helping citizens in Singapore live, work and play in an era dominated by phenomenal advancements in computing technology, telecommunications, biotechnology, nanotechnology and alternative energy as well as critical environmental issues. Another consideration was the need for students to develop twenty-first century competencies that would enable them not only to be consumers of knowledge but also to be able to apply, transfer and create knowledge. These goals required a science education that supported flexibility of the mind, innovation and creativity. Then Minister for Education Mr. Tharman Shanmugaratnam, in his annual address to principals, teacher educators and education policy makers at the Ministry of Education (MOE) 2005 work plan seminar, reiterated this: 'We are progressively shifting the balance in education, from learning content to developing a habit of inquiry.... To engage them and prepare them for life than to prepare for tests and examinations' (Ministry of Education, Singapore [MOE], 2005).

Beyond curricular aspirations, this shift towards inquiry took time and resources to take root in practice. A science head of department (HOD) highlighted teachers' instrumental roles as well as their changing understanding and practices in supporting students in learning science as inquiry:

> Teachers need to invest quite a lot of time in inquiry lessons – questioning, assessing, linking what has happened in lessons towards explanations and learning outcomes...to make the most of the exploration phase, linking what children have discovered and allowing them to make use of that evidence to build explanations. Often, teachers are at the phase of carrying out hands-on activities and not inquiry based activities. But gradually, I see more teachers using questions that build understanding. Overall, teachers understand more about the benefits of using inquiry lessons. (Madeline, survey, 5 Jul 2012)

And while this chapter is being written, the new 2014 primary science curriculum is taking shape. 'Essential takeaways' would augment 'key inquiry questions' to better support teachers and students in uncovering the big ideas at the heart of each theme. The aspiration is towards a deeper and wider practice of inquiry, driven by classroom teachers.

Partnership in Curriculum Design and Implementation in Primary Science

Having provided an overview of the evolution of the primary science curriculum in Singapore, we now turn to a discussion of the partnership framework of curriculum design and implementation. Posner (1998) suggested that there are three common approaches to curriculum development. The 'procedural approach' or 'technical production approach' focuses on the procedures or steps of curriculum development (e.g., Schwab, 1970; Taba, 1962; Tyler, 1949). The 'descriptive approach' or 'events and decision-making approach' is about what curriculum planners actually do, including events that occur and decisions which are made (Walker, 1971). Finally, the 'conceptual approach' or 'levels of planning approach' examines elements of curriculum planning, implementation and evaluation and how the elements relate to one another (Goodlad & Richter, 1977; Johnson, 1977). Jackson

(1992) viewed this categorisation of curriculum approaches as not mutually exclusive but as a way of connecting thought and action based on the interest and experiences of people working on the curriculum.

Science curriculum development in Singapore has features of the three curriculum approaches highlighted by Posner (1998). This blended approach includes the adoption of a curriculum development process, working with different stakeholders to execute the various stages of the curriculum development process and making decisions based on the information and feedback gathered from a variety of sources and stakeholders. We will elaborate on the framework, features, challenges and possibilities of curriculum partnership in the following sections:

(a) Partnership framework of curriculum design and implementation
(b) Features supporting partnership framework
(c) Challenges and possibilities in partnership in teacher learning

Partnership Framework of Curriculum Design and Implementation

Central to Singapore's framework of curriculum design and implementation in primary science is the close partnership among curriculum developers, school leaders, science educators and practitioners. Figure 2.3 is our diagrammatic representation of this partnership process (inner concentric ring) interacting with the actors involved in the partnership (depicted in the outer circle where they can be involved in one or more stages of the curriculum design and implementation process). A brief description of the partnership framework follows.

- *Scanning literature and practices in primary science*. This process includes the scans of literature and practices locally and internationally by curriculum planning officers. Partners from the National Institute of Education (NIE) also contribute research knowledge of other education systems. Educators and practitioners from the various international schools in Singapore also share about their curriculum and how these were translated into practice. These scans of literature and practices provided useful insights on efforts in curriculum, pedagogy and assessment in the different education systems.

  A curriculum review committee member shared that the understanding of how the aims of primary science education were translated into curriculum learning outcomes and classroom practice in different education systems was valuable in informing the curriculum review:

  > I appreciate the rigour put into thinking through the aims, objectives and the conceptual framework of the curriculum during the review, the thoughts and thorough discussions in the currency, appropriateness of the knowledge and processes that are taught and also the study of existing curricula from the many countries and way the curriculum could support the practice and implementation in particularly. (Angie, survey, 21 Jul 2012)

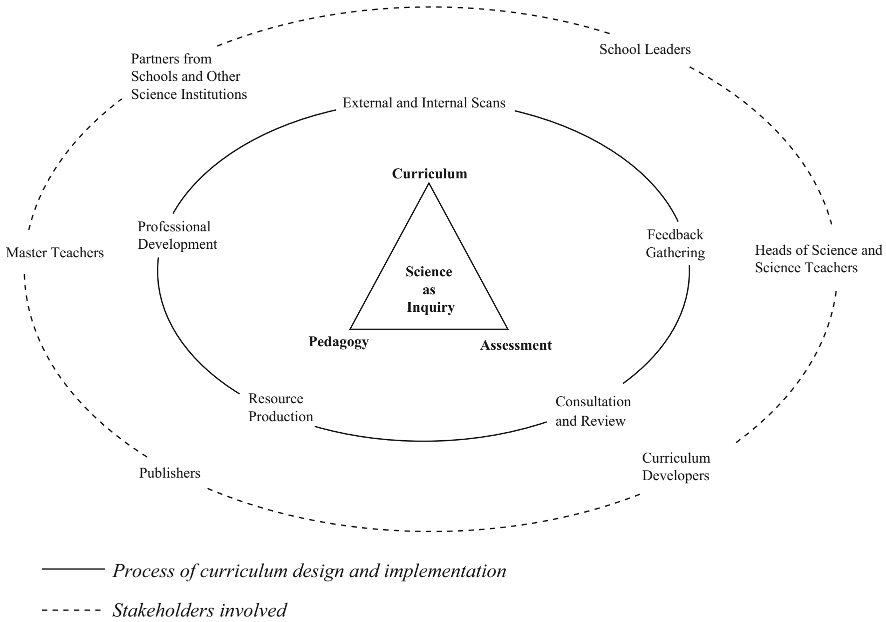

Fig. 2.3 A partnership framework of curriculum design and implementation of primary science in Singapore

- *School leaders and practitioners providing feedback on the existing curriculum.* In the feedback gathering process, at least one school leader (e.g., head of department) or teacher from each of the 178 primary schools participate in the pre-draft and/or post-draft focus group discussions. They provide useful feedback not only on the syllabus content but also on pedagogy, assessment and implementation issues. What is especially valuable is the sharing of personal experiences on curriculum implementation such as the following by a science HOD on how inquiry-based learning supported and motivated learning and thinking:

  I see great interest in children for science – as it is one subject which is strongly linked to life and inquiry allows many skills and attitudes to develop. I found that children who are taught using inquiry always talk about turning into thinkers. They also become motivated to learn (this success spills over to learning other subjects) and they look forward to challenges. That interest can later on blossom into true passion – not necessarily in science but in learning. (Madeline, survey, 5 Jul 2012)

- *Consulting expert panel of curriculum developers, school leaders, science educators and practitioners.* This consultative process involves the convening of a curriculum review committee of experts and practitioners from the different institutions including the Academy of Singapore Teachers, the NIE, various departments (such as Educational Technology Division, Gifted Education Branch) and schools from MOE and the Singapore Examinations and

Assessment Board (SEAB is a government-funded independent Board that develops and administers national examinations). This close collaboration between the various stakeholders facilitates alignment of the principles, spirit and objectives of the curriculum with pedagogy and assessment (school-based and national assessments). A former curriculum specialist also highlighted the role of the panel in ensuring the coherence of curriculum development across levels of development, guided by the concept of a spiral curriculum where concepts are revisited in greater depth (Bruner, 1960):

> The concept of a spiral curriculum in which topics are revisited in greater depth at a later stage, even onto the secondary level. (Helen, survey, 12 Aug 2012)

- *Consulting senior educators and administrators on curriculum and implementation plans.* The proposed curriculum and implementation plans are discussed with a panel of senior educators and administrators from the Ministry of Education Headquarters. This consultative and approval process attempts to align the science curriculum to the overall goals of education and garner the necessary buy-in and support for resource allocation to implement changes.
- *Producing textbooks and resources, with reviews by school practitioners.* The resource development process involves the heads of science and science teachers in the textbook/resource review and approval process. This process gathers feedback on how the planned curriculum could be translated into learning experiences in everyday classroom contexts, in the textbooks (e.g., developed by publishers) and resources (e.g., developed by curriculum planning officers with teacher practitioners). Teachers provide reality checks on the feasibility of suggested teaching and assessment strategies and activities to support student learning.
- *Supporting professional development in collaboration with the Academy of Singapore Teachers, the NIE and schools.* The support for curriculum implementation includes working with the NIE in providing pre-service and in-service professional developments to support teachers in understanding and implementing the curriculum. The partnership with master teachers from the Singapore Academy of Teachers to foster pedagogical leadership focuses on teacher collaboration and leadership in learning communities within and beyond schools in professional networks. The long term goals of these collaborations are to raise the standards of practice in the classroom, thereby strengthening the culture of teaching excellence.

Besides the professional development opportunities provided by various partners, partnering schools in establishing ongoing communication channels and organising sharing platforms at various levels (national, zonal, cluster and school levels) also support teachers in curriculum implementation. Curriculum specialists from the Curriculum Planning and Development Division who developed the curriculum also join teachers in their lessons to observe and discuss issues and challenges during curriculum enactment.

Features Supporting Partnership Framework

From the responses in the questionnaire and in-depth interviews, we surface some features that our partners felt were important in supporting the partnership framework:

(a) Anchoring the review in the science curriculum framework
(b) Mechanisms that tap on multiple perspectives and experiences of various stakeholders
(c) Working with different partners in supporting different stages of the curriculum cycle
(d) Teachers as key curriculum partners in gathering local classroom-based evidence to inform curriculum review and implementation

Anchoring the Review in a Science Curriculum Framework

Many partners highlighted the importance of the science curriculum framework (Fig. 2.2) in guiding the curriculum review as it clarified the philosophy and broad goals of science education for the different partners. A member of the curriculum review committee who was a principal master teacher explained how the science curriculum framework served as a common compass that guided the curriculum design and review:

> I thought it is important to have a conceptual framework to curriculum, what needs to be learnt, what helps to facilitate the learning, what helps to understand the learning and most importantly, how the curriculum could build that spirit and processes of scientific mindset and literacy in the students so that they can function effectively as a science-literate person. (Ada, survey, 21 Jul 2012)

Marsh (2009) highlighted that one of the advantages in having a curriculum framework was to ensure coherence in the curriculum across levels and therefore the framework serves as a guiding post for partners. He cautioned against, however, having too much details in the framework which could hamper new ideas and flexibility at the point of curriculum design and also at the point of classroom implementation. It would be important to keep the curriculum framework sufficiently broad to provide a guide for partners in the curriculum review and implementation. At the same time, teachers should be supported in understanding and translating the understanding of the curriculum framework into the design of everyday learning experiences.

Mechanisms That Tap on Multiple Perspectives and Experiences of Stakeholders

Another essential feature of our partnership framework is the mechanisms that tapped on the multiple perspectives and experiences of stakeholders. In our case, we have broad-based mechanisms such as school questionnaires and feedback forms to tap on the broad swath of perspectives from all our primary schools. We also mount focus group discussions to tap deeper into teachers with varying years of teaching experiences and across the different grade levels. These focus group discussions provided not only insights on the science curriculum but also critical issues of enacting the curriculum. The importance of gathering multiple perspectives from teacher practitioners to better support curriculum implementation was highlighted by a primary school head of science:

> With the input from the teachers, the team looked at improving the syllabus for better clarity in communicating the intent to the teaching fraternity. There was deliberation on how the curriculum could be improved, for better classroom implementation. In this respect, input from the teachers are highly valued... as a teacher then, being involved in the review of the curriculum, I was able to appreciate the diversity of views and concerns expressed by different teacher representatives.(Wendy, survey, 12 Jul 2012)

The curriculum review committee, with partners from schools and the NIE, provided another layer of expertise and discipline knowledge and perspectives in curriculum, pedagogy and assessment. For instance, some gave input on the appropriateness of the depth and breadth of knowledge as well as the cognitive processes of learning. Others shared thoughts and views on how science inquiry could be integrated into the learning content and processes as well as how it could be facilitated and assessed in the classroom. Suggestions on the resources that could be used to facilitate the learning of science in the schools were also important inputs. A curriculum review committee member shared how she leveraged on her experiences in both primary and secondary school teaching to contribute to the curriculum review:

> Having taught science in secondary schools and supported science learning in both primary and secondary schools, I brought school-based science teaching and learning as well as assessment practices for the curriculum review committee to consider when we relook at currency, effectiveness and relevance of the curriculum ... I brought the practice into the curriculum review process, the science concept/knowledge (from science teacher perspectives) and the connections with assessment (feedback/inputs of learning) and resources (from a perspective of connecting learning to assessment and teaching strategies and resources).(Angie, survey, 21 Jul 2012)

Such a consultative approach in the curriculum review process in Singapore is supported by research on supporting change in educational practice (Fullan, 1982). Hart (1989) also reported that the analysis of the discrepancies between practice and policy resulted in changes in policy recommendations in Canada. This illustrates how the current ideas, research and practice in science education can be synthesised collaboratively.

Working with Different Partners in Supporting Different Stages of the Curriculum Cycle

In giving more agency to the different stakeholders of education, the curriculum review process values the contributions and inputs by various partners. However, we also recognise that in practice we could not involve *all* partners at *all* stages of the curriculum cycle. This would drain much of the resources and also tax too heavily on the time of our partners. Our partnership framework therefore acknowledges the need to strategically tap different partners at the different stages of the curriculum cycle. For example, in the recent 2008 curriculum cycle, the curriculum developers worked with teachers from schools and master teachers to design activities to support science teaching and learning as inquiry. They also worked with teachers and the Science Centre Singapore (SCS) to develop teachers' ideas into Science Teaching and Resource (STaR) kits to support the use of hands-on learning for students. The resources were used at both the NIE pre-service and in-service courses to support teachers in curriculum implementation.

In another example, schools partnered each other in curriculum implementation. Insights from a recent collaborative effort of a cluster of primary and secondary schools highlighted the value of teachers from the primary and secondary schools coming together as partners to observe and discuss student learning. Through pedagogical dialogue of classroom practices focused on student learning, teachers better understood the learning needs and misconceptions of students and how to better scaffold student learning across the primary and secondary science curricula. Such school-based partnership efforts not only supported teachers in understanding the progression of science learning beyond the primary level but built teachers' capacity as curriculum leaders.

Teachers as Key Curriculum Partners in Gathering Local Classroom-Based Evidence to Inform Curriculum Review and Implementation

Our partnership framework regards teachers as key partners in gathering local classroom-based evidence to inform their enactment of the curriculum. We recognise that teachers empowered to collect and make meaning of classroom data and information can make better decisions on how the curriculum can remain current and relevant for students and how learning can be more impactful (Cochran-Smith & Lytle, 1999; Crawford & Cornett, 2000; Hong & Lawrence, 2011). For example, data and information on how the curriculum impacted learning provided useful insights for teachers to design different teaching and assessment strategies that better supported students with different learning dispositions and aptitudes.

Teachers who played an active role in gathering classroom-based evidence of student learning had an added advantage in informing how teachers themselves could be better supported in resource provision and professional development. A master teacher shared how partnerships involving teachers in designing and field testing resources not only provided classroom-based evidence but also benefitted the curriculum developers, master teachers, heads of department and teachers who were involved in the process of resource design and curriculum implementation:

> The materials were planned with teachers and trialed in the classrooms by teachers and feedback given by a team of teacher-observers... Process was rigorous and thorough, which benefited all who were involved in it. (Ivy, survey, 12 Sep 2012)

Providing materials that are aligned to new curricula is generally recognised as important in supporting successful reforms. Adey (2004), however, cautioned that providing curriculum resources is not sufficient in themselves. A critical ingredient in designing the resources is the personal involvement of teachers who are the users of the resource. In their study of the use of CASE (Cognitive Acceleration in Science Education) materials to support science teaching, Shulman and Shulman (2004) found that teacher ownership of the resources was key to sustaining practice. Teachers, therefore, are important partners in resource development in the curriculum implementation process. These curricular resources can then play a key role in initiating and sustaining change because they are 'concrete, tangible vehicles for embodying the essential ideas of a reform' (Powell & Anderson, 2002, p.112).

Challenge and Possibilities in Partnership in Teacher Learning

While the partnership framework has enhanced the curriculum design and implementation processes, school leaders, teachers and partners from the various institutions have identified one process that is fundamental and requires more attention and further thinking. This is in the area of partnership to enhance teacher professional development that will in turn strengthen curriculum implementation. We have been exploring this issue and would like to share some thoughts on this.

In Singapore, the professional development effort draws on the partnership of many different groups of professionals to conduct formal workshops and sharing. These professional development activities have helped build teacher competencies in science teaching. However, there are limitations to 'one-off' workshops. Fullan and Stiegelbauer (1991) found that teachers often encountered difficulties in transferring experiences in one-off workshops to the realities of their own classrooms. Gusky (2000) also found that short one-off workshops often could not impact change at the level of belief and values and therefore were less effective in sustaining curricular changes.

Hence, educators and researchers are increasingly studying efforts in teacher learning opportunities beyond 'one-off' professional development (Clarke & Hollingsworth, 2002; Hoban, 2002) where teachers are active learners shaping their own professional growth as reflective practitioners (Schon, 1983). Shulman and Shulman (2004) have argued for a community-based approach to proliferate and sustain teacher learning. In their teacher learning model of Vision, Motivation, Understanding, Practice, and Reflection, they suggested that schools create environments that support, sustain and 'tune' the visions, understandings, performances, motivations and reflections of all its members to encourage learning. This goes beyond individual teachers' learning to a conception of teacher learning within a broader context of the community. We felt that this idea of community-based teacher learning is consistent with the partnership principle of curriculum design and implementation, where teachers are regarded as 'equal' partners creating the knowledge and environment to bring about change in the enactment of the curriculum. We would, therefore, have to evolve the current roles of the 'partners' in the teacher professional development process in our framework to reflect a stronger learning towards teacher learning within a community.

Spillane, Reiser, and Reimer (2002) argued that teachers are sense-making agents and that both formally structured social contexts and informally created social contexts therefore affect how teachers make sense of reforms, providing a shared base of beliefs and knowledge that teachers use to reason about implementation. Hoban (2002) and Adey's (2004) work has informed us that teachers providing curriculum leadership as part of a learning community could strengthen ownership and motivation to improve practices. We observe that some schools in Singapore have begun fostering the formation of professional learning communities to drive change in teaching, learning and assessment practices. Such ground-up curriculum leadership among teachers offers potential to address the challenge of effective professional development partnerships in curriculum implementation. We hope to further work on this aspect of teacher learning vis-à-vis the curriculum partnership framework. Such insights would contribute to the understanding of how teacher learning opportunities affect teaching practices and student outcomes as well as how teachers learn successful practices. This is an area which Darling-Hammond and Bransford (2005) reported to be lacking in the field of teacher learning and practice.

Looking Forward

This chapter documents an original primary science curriculum partnership framework which has features of three common approaches to curriculum development – 'procedural approach', 'descriptive approach' and 'conceptual approach' (Posner, 1998, pp. 79–100). We hope that insights gleaned on how different stakeholders were involved across various stages of the curriculum design and implementation process would be useful in driving stronger collaboration and ownership of curricular change in the classroom.

We also hope that this chapter will help science teachers reflect on their own changing and important roles as curriculum partners and leaders of inquiry in the classroom. The documentation of the framework provides a common set of terminology for conversations around partnership in curriculum design and implementation and we look forward to having rich dialogues with our partners in the science education community.

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