Chapter 9
Singapore Science Education

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Abstract Singapore is a small country with a total land area of about 716 km^2 and a population of about 5.4 million, comprising 3.8 million citizens and permanent residents and 1.5 million foreigners. Apart from her deepwater harbour, the only other natural resource that Singapore has is her people, so the education and development of the people is crucial to the prosperity and progress of the country. Thus the education system in Singapore aims to help the young to discover and develop their talents and potential to the fullest, and cultivate a passion for lifelong learning. To achieve these aims, the educational system is becoming more flexible, diverse and broad-based, and these characteristics are also reflected in the teaching and learning of science in Singapore. The science curriculum, from the primary to high school levels, is centred on science as inquiry and focusses on the knowledge, skills and processes, ethics and attitudes required in the practice of science, as well as the understanding of the impact of science in daily life, society and environment. It seeks to cultivate the scientific literacy, competencies and values necessary for the young to take on challenges, present and future, and thrive in a fast changing world.

9.1 Introduction

Singapore is a sovereign city-state with a land area of 716.1 km^2, and a total population of 5.4 million, of which 3.31 million are Singapore citizens and 0.53 million are permanent residents (Department of Statistics Singapore 2013). Apart from its strategic position fronting the Straits of Malacca, its deepwater harbour and its people, Singapore has very few natural resources and has to import almost everything that it needs. Thus, the country places great importance on the education and development of its people as they are crucial to nation building and the

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economy of the country. A key function of the educational institutions in Singapore is to build the workforce required for its high value, technology-intensive manufacturing industries and its world-class service sector to meet its Global-Asia hub aspirations (Ministry of Trade and Industry Singapore 2012). The Singapore government's commitment to education can be seen in the allocation of SGD 11.6 billion (about USD 9.1 billion, or 20 % of total government expenditure) to education for the financial year 2013, the second highest government expenditure after defence, with a total of SGD 5.6 billion going to the national primary, secondary, pre-university and special education schools and a total of SGD 5.1 billion for six local universities, five polytechnics, one institute of technical education and two tertiary institutions for the arts (Ministry of Finance Singapore 2012).

9.2 Singapore Education System

The education system in Singapore seeks to help "students to discover their own talents, to make the best of these talents and realise their full potential, and to develop a passion for learning that lasts through life" (Ministry of Education Singapore 2013d) as well as to support economic growth and nation building (Ministry of Education Singapore 2010a). In the national school system in 2012, there were 14,000 teachers and 246,000 students in 175 primary schools (Primary 1–6), 13,000 teachers and 184,000 students in 154 secondary schools (Secondary 1–5), 3000 teachers and 38,000 students in 15 mixed level schools (primary and secondary or secondary and pre-university) and 2000 teachers and 20,000 students in 13 institutions catering for pre-university students (Ministry of Education Singapore 2013a).

Primary school education is compulsory in Singapore. After 6 years of primary schooling (Grades 1–6), a student proceeds on to 4 or 5 years of secondary school education (equivalent to Grades 7–10). There are various pathways of study for post-secondary education. About one-fifth of each school cohort enrols into the Institute of Technical Education for one to two years of vocational education (Ministry of Education Singapore 2011a). More than 4 in 10 students go on to pursue a 3-year diploma programme in a polytechnic or institution for the arts. The rest continue their study for 2 or 3 years in a pre-university institution (equivalent to Grades 11–12). About a quarter of each school cohort studies at one of the five local autonomous universities funded by the government. The plan is to increase this to about 40 % by 2020 (Ministry of Education Singapore 2012b). Another one-fifth of the cohort enrols in privately funded local universities or universities overseas.

9.3 Development of the Singapore Education System

The Singapore education system has undergone three phases of development and is now into its fourth phase. The first three phases that the country has undergone, from the time it became self-governing in 1959 and independent in 1965, are the survival-driven phase in 1959–1978, the efficiency-driven phase in 1979–1996, and the ability-driven phase in 1997–2011 (Goh and Gopinathan 2008; Ministry of Education Singapore 2010b). The survival-driven phase focussed on “the development of a literate and technically trained workforce” (Goh and Gopinathan 2008, p. 14) to support the country’s shift from entrepôt trade to export-oriented industrialisation and to attract multinational corporations to Singapore in order to ensure its economic survival. This resulted in much emphasis being placed on bilingualism, mathematics, science and technology education, as well as vocational training, to provide workers with the competencies required for the new industries being set up during the period.

In the late 1970s, although economic prosperity was evident in Singapore, there was a realisation that the country had to move away from labour-intensive industries into higher technology, capital-intensive areas as other developing countries had a greater labour cost advantage over Singapore (Goh and Gopinathan 2008; OECD 2011). This meant that the strong emphasis on mathematics, science and technical education which was started in the earlier phase was maintained. In addition, Singapore embarked on an efficiency-driven education system in 1979 to address the high attrition rates in schools and the low levels of English language proficiency, which affected the learning of other subjects and contributed to the attrition rates. Streaming of students into different academic tracks was introduced to allow them to progress at a pace that was more appropriate to the individuals (Ministry of Education Singapore 2008a; OECD 2011). The national curricula and assessments were also revised “to enable each pupil to go as far as possible in school, and thereby achieve the best educational takeoff for training and employment” (Goh and Gopinathan 2008, p. 23). The changes resulted in a reduction in the school attrition rate. By 2009, only 1.2 % of each cohort did not complete secondary education, compared to dropout rates of 6 % among primary school students and 13 % among secondary school students in the 1970s (Ministry of Education Singapore 2012b). At the end of the efficiency phase, Singapore students took part in the Third International Mathematics and Science Study in 1995 and emerged among the top performing countries for both Grades 4 and 8 (TIMSS International Study Center 1996, 1997).

Rapid globalisation and technological advances led to the transition to a knowledge-based economy for Singapore. The education system responded and entered into its third phase, the ability-driven phase, from 1997 to 2011 (Goh and Gopinathan 2008) to better prepare the young to meet the challenges of the twenty-first century and instil passion for lifelong learning. The key features of this approach were “maximal development of talents and abilities, and maximal harnessing of talents and abilities” (Ministry of Education Singapore 1998). The approach was implemented by encouraging schools to develop innovative programmes and differentiated curricula as well as through the provision of multiple pathways for a child to realise his/her potential (Ministry of Education Singapore 2010a). These multiple pathways include greater opportunity for lateral transfer between different academic tracks, integrated programmes for high-ability students (Ministry of Education Singapore 2011b) and specialised schools for science and mathematics, science and technology, the arts, sports, as well as for students who are more inclined towards vocational learning (Ministry of Education Singapore 2012a).

The fourth and current phase of educational development—the student-centric, values driven phase—was launched in 2011 to build upon the ability-driven phase and with a stronger focus on the holistic development of the child "centred on values and character development", while maintaining the rigour of the curriculum and ensuring that there is a diversity of pathways and opportunities for educational and career progression (Ministry of Education Singapore 2011c). Schools began developing applied learning and learning for life programmes for their students to help them apply thinking skills and knowledge across all subjects to real-life situations, and to provide "real-life experiential learning to develop their character and values, cultivate positive attitudes, self-expression and strengthen their people skills" (Ministry of Education Singapore 2013b). Areas in which applied learning programmes could be developed include engineering and robotics, environmental science and technology, and health services, while programmes for learning for life could include outdoor adventure learning and sports (Ministry of Education Singapore 2013b).

9.4 Science Education in Singapore

Science education mirrored the transformation that took place in the general education landscape in Singapore. In the early years of national survival, science education played a key role in developing skills and capabilities that fuelled the industrialisation process. Standardisation was a hallmark of the efficiency-driven phase. Science textbooks, workbooks and teaching guides were locally published for the first time, and large numbers of teachers, including those with little science education background, were trained to teach science using these resources. This helped to ensure that a certain minimum level of fidelity in curriculum implementation was maintained (Poon 2014).

The ability-driven phase saw the need for nurturing inquiring minds and citizens comfortable with using and harnessing technology for work and leisure in the twenty-first century. Carrying over into the current student-centric, values-driven phase, there is a continued drive for inquiry coupled with a new emphasis on applying knowledge to new contexts to solve real-life problems. The current stated goal of science education is to enable "students to be sufficiently adept as effective citizens, able to function in and contribute to an increasingly technologically-driven world" (Ministry of Education Singapore 2012c, p. 1). The development of scientific literacy in students is part of the twenty-first century competencies framework adopted by the Ministry of Education Singapore to prepare students to "thrive in a future driven by globalisation and technological advancements" (Ministry of Education Singapore 2010c). The Singapore science curriculum framework is implemented through a "science as an inquiry" platform and it includes the "integral domains of (a) Knowledge, Understanding and Application, (b) Skills and Processes and (c) Ethics and Attitudes" (Ministry of Education Singapore 2012c, p. 1). Both the student and the teacher are involved in the inquiry process with the student as the inquirer who determines ways to solve problems by asking appropriate questions, planning and conducting experiments, analysing the data collected, drawing conclusions, communicating and defending their findings (Chinn and Malhotra 2002). The curriculum positions the teacher as the leader of inquiry (Ministry of Education Singapore 2012c), facilitating the inquiry process in the classroom and encouraging the student to explore novel situations, build new understandings, and apply his/her knowledge and skills to solve problems relevant to daily life.

Through three waves of the Information, Communications and Technology (ICT) Masterplan since 1997, ICT has been innovatively harnessed as a tool for enhancing teaching and learning. In particular, innovations in the use of ICT centred on learning of twenty-first century competencies, self-directed learning, and collaborative learning (Ministry of Education Singapore 2008b, c). As such, the development of ICT tools, such as multi-player games, virtual reality and mobile technologies are strongly encouraged, and education labs and schools (e.g. FutureSchools@Singapore) have been established for this purpose. There is also a dedicated translational unit to scale up the use of innovative practices in the school system.

9.5 Primary Science

Unlike most education systems around the world, students in Singapore first encounter formal science lessons at the age of nine, in the third year of primary schooling (Primary 3). English is the main language of instruction in school, but is not the predominant language spoken at home. Therefore, there is a strong focus on literacy development in the first two years of primary education to build a firm foundation for students to read to learn (Chall 1983, 1996). Curriculum time allocated for science, which ranges from two hours per week in Primary 3 to two and a half hours per week in Primary 6, is also lower when compared to that of mathematics and English (see comparison at G4 in Mullis et al. 2012a, b).

The aims of the national primary science curriculum are to give students the experiences, knowledge and opportunities "to stimulate their curiosity about their environment", to "understand themselves and the world around them", "develop

Table 9.1 Overview of the 2014 primary science syllabus

Themes	Key inquiry questions	Lower block (Primary 3 and 4)	Upper block (Primary 5 and 6)
Diversity	• What can we find around us? • How can we classify the great variety of living and non-living things? • Why is it important to maintain diversity?	• Diversity of living and non-living things (General characteristics and classification) • Diversity of materials	
Cycles	• What makes a cycle? • Why are cycles important to life?	• Cycles in plants and animals (Life cycles) • Cycles in matter and water (Matter)	• Cycles in plants and animals (Reproduction) • Cycles in matter and water (Water)
Systems	• What is a system? • How do parts/systems interact to perform function(s)?	• Plant system (Plant parts and functions) • Human system (Digestive system)	• Plant system (Respiratory and circulatory systems) • Human system (Respiratory and circulatory systems) • Cell system • Electrical system
Interactions	• How does man better understand the environment? • What are the consequences of man's interactions with the environment?	• Interaction of forces (Magnets)	• Interaction of forces (Frictional force, gravitational force, force in springs) • Interaction within the environment
Energy	• Why is energy important? • How is energy used in everyday life? • Why is it important to conserve energy?	• Energy forms and uses (Light and heat)	• Energy forms and uses (Photosynthesis) • Energy conversion

Source Ministry of Education Singapore (2013e)

skills, habits of mind and attitudes necessary for scientific inquiry", use "scientific knowledge and methods in making personal decisions", and "appreciate how science influences people and the environment" (Ministry of Education Singapore 2013e, p. 5). The overview of the primary science syllabus is given in Table 9.1. A thematic approach is adopted in the primary science syllabus to present an integrated perspective of scientific ideas. The five themes of Diversity, Cycles, Systems, Energy and Interactions are chosen to embody concepts in both the life and physical sciences.

Key inquiry questions and essential takeaways are also spelt out in the primary science syllabus to help teachers and students understand the big ideas and key concepts in each theme. In the theme of Diversity, for example, the Key Inquiry Questions focus on the components of the environment, the diversity of living and non-living things and the importance of maintaining such diversity (Ministry of Education Singapore 2013e). Instead of memorising classical taxonomy of living things, the syllabus encourages students to observe similarities and differences in the characteristics and properties of living and non-living things in their classrooms, homes, school gardens or nearby public parks. They learn about ways of classifying using dichotomous keys, and the usefulness and applications of classification. Students learn about the nature of science when they understand that classifications, like the ones that scientists give to groups of objects, are not permanent and that advances in technology could modify properties of materials or create new materials to suit different uses. For example, students observe that boat models made from paper disintegrates and sink in water but paper cups can hold water, so the properties of paper are not fixed but can be modified to cater to the intended use of the paper. Key inquiry questions are developed for all the other themes and are shown in Table 9.1.

The syllabus also suggests specific teaching and learning strategies to engage students' interest in science, including activities using concept cartoon, concept mapping, role play, stories, field trips and so on. Teachers are encouraged to incorporate experimental investigations. An example of the inquiry experiments include determining the factors that affect the rate of evaporation and investigating whether the material of the cloth (e.g. cotton or Dri-FIT) affects the rate of evaporation. Students could also make a model of the human lungs, study the movement of water in a plant, explore how heart rate changes with exercise, compare cheek and onion cells, and discover the components of an electrical circuit and how they interact in the circuit. Professional development programmes such as the Advanced Diploma in Primary Science Education conducted by the National Institute of Education Singapore (National Institute of Education Singapore n.d.) enable teachers to learn how to use these activities in their own classroom teaching to engage their students.

In Primary 5, school-wide subject-based banding of students is implemented with students who are stronger in certain subjects, including science, to learn the subject at the standard level. If students are weaker in certain subjects, they can learn the subjects at the foundation level, which is less demanding for them. For example, in foundation science, students do not have to learn the cell system, force in springs, and energy conversion, which are included in the standard science syllabus. Generally, more curricular time is allocated to the learning of each topic in foundation science and pedagogical approaches are also chosen to meet the needs of the students. The object of the subject-based banding is to cater to the different abilities of the student, to allow them to learn more in the subjects that they are strong in while ensuring that all students, regardless of ability, learn the fundamentals well (Ministry of Education Singapore 2013c).

9.6 Lower Secondary Science

All students in lower secondary (Grades 7–8) will learn science, which is designed as a general integrated science syllabus to develop students' scientific literacy. Lower secondary science builds upon what students learn in primary science. The aims of lower secondary science are to "cultivate students' perception of Science as a collective effort and a way of thinking rather than just a body of facts", engage them in "Science-related issues that concern their lives, the society and the environment" and "help students develop the domains that are integral to the conduct of Science Inquiry" (Ministry of Education Singapore 2012c, p. 5). Strategies recommended by the curriculum developers to achieve these aims through inquiry-based learning include brainstorming, case study, concept cartoons and mapping, collaborative learning, field trips, model building, project work and role play. The curricular time allocated to science in Secondary 1 and 2 is about three and a half hours per week.

In addition to scientific knowledge, skills and attitudes, students continue to learn more about the nature and practice of science, and the links between science, technology, society and environment in a section on The Scientific Endeavour and through the entire four themes of Diversity, Models, Systems and Interactions. As Singapore adopts a spiral curricular design, many of the lower secondary science topics in the three themes of Diversity, Systems and Interactions are coherently developed from the primary science syllabus (see Table 9.2). Consistent with the primary science curriculum, the lower secondary science curriculum is inquiry-centric. Key Inquiry Questions in the lower secondary science syllabus serve to guide students and teachers to explore the big ideas and important concepts in the themes (Ministry of Education Singapore 2012c). Again, teachers are encouraged to help students make links between the concepts taught in the different themes to reduce compartmentalisation of knowledge.

The Scientific Endeavour is a new strand introduced in the 2013 Lower Secondary Science syllabus. It incorporates the topics of "scientific inquiry" and "science and technology in society" from the 2008 syllabus and introduces elements of the nature of science. Lederman (2007) describes the nature of science as "ways of knowing, or the values and beliefs inherent to scientific knowledge and its development" (p. 833). Prior to 2013, the study of the nature of science was not common among Singapore schools (Tan et al. 2006) and was not explicitly articulated in previous science syllabuses. These changes in the syllabus bring it in line with research on the importance of incorporating epistemic discourse and dialogical reasoning (Kelly 2008) and on the nature of science into school science (Abell and McDonald 2004; Bybee 2004; Lederman 2007). The learning outcomes include developing awareness that science is a human endeavour that is socially constructed based on systematic collection and analyses of evidence and rigorous reasoning. Students are exposed to the idea that scientific evidence can be subjected to multiple interpretations and that claims and supporting evidence must stand up to scrutiny by the scientific community. Students are encouraged to develop attitudes such as

Table 9.2 Overview of the lower secondary science syllabus

Themes	Topics	Key inquiry questions
The scientific endeavour		• Why did this event, phenomenon or problem happen? • What is science? • How does science affect our lives?
Diversity	• Exploring diversity of matter by their physical properties • Exploring diversity of matter by their chemical properties • Exploring diversity of matter using separation techniques • Understanding diversity of living things	• How does the diversity of living and non-living things contribute to our lives? • How do we classify things in our world? • How do we find out the properties and characteristics of things around us?
Models	• Model of cells—the basic units of life • Model of matter—the particulate nature of matter • Model of matter—atoms and molecules • Ray model of light	• Why are models important? • How do we know that the models used are good representations of the real system?
Systems	• Transport system in living things • Human digestive system • Human sexual reproductive system • Electrical systems	• How do parts of a system or different systems work together to perform a function? • How could parts of a system affect the function of other parts?
Interactions	• Interactions through the application of forces • Energy and work done • Transfer of sound energy through vibrations • Effects of heat and its transmission • Chemical changes • Interactions with ecosystems	• How does knowledge of interactions between and within systems help man better understand his environment? • What are the interactions between physical phenomena and life processes?

Source Ministry of Education Singapore (2012c)

integrity, open-mindedness and perseverance in carrying out scientific inquiry. Topics such as genetically modified food, nuclear energy, and clearing of forests for agriculture are used as authentic and engaging contexts for students to reflect and debate on the social and ethical issues arising from the impact of science and technology on society, especially when there are conflicting claims on the same issue. The Scientific Endeavour is not taught only as a standalone topic, but is also infused and integrated into the teaching of the other four themes.

Diversity in lower secondary science builds upon what students have learnt in primary science about the diversity of living and non-living things, and they explore how such diversity contributes to their lives (Ministry of Education Singapore 2012c). For example, in addition to the learning of the properties and uses of materials, they also discuss sustainable use of materials and the environmental impact of some materials such as paper and plastics. More chemistry concepts are introduced in lower secondary science as compared to primary science. They learn about elements, compounds and mixtures, solubility of substances and simple separation techniques.

In terms of pedagogical approaches, field trips lend themselves well to the teaching of diversity. For example, the Bukit Timah Nature Reserve (National Parks 2009), a primary forest, and the Sungei Buloh Nature Reserve (Sungei Buloh Wetland Reserve n.d.), a mangrove swamp, are excellent places that students can experience biodiversity in Singapore and learn how flora and fauna interact with each other in the respective ecosystems. Singapore has also been building technology enriched resources for the teaching and learning of science. For example, *Legends of Alkhimia* (Chee and Tan 2012) is a locally developed game-based learning tool that provides students with an immersive environment to inquire into the basic concepts involved in the separation of mixtures. The game provides the context and motivation for learning, and the virtual in-game laboratory allows students to try out various ways of separating mixtures and gain virtual experience of the consequences of their actions that might otherwise be dangerous to them. Students can thus, carry out the 'wrong' procedures and find out why these procedures are not suitable or less desirable than the 'right' methods, something which is not encouraged in normal practical work because of safety considerations. As such, the virtual learning platform provides opportunities for students to make and learn from their mistakes.

The theme, Models, is not encountered in primary science, a possible reason being that the concepts associated with the theme may be too abstract for younger students. The lower secondary students need to know that a model is not a true description of a phenomenon or entity, "but rather a set of assumptions that include theoretical entities and relations among them" (Snir et al. 2003, p. 797) to help people to describe, think and make predictions about a phenomenon or entity. Students learn the model of cells, the particulate nature of matter, models of atoms and molecules, and the ray model of light. They will already have some basic knowledge about the structure of a cell and the functions of the various parts of the cell, as well as some properties of light. More advanced skills such as the use of a microscope to observe and identify cell parts, and concepts such as the reflection, refraction and dispersion of light are taught at this level. However, the chemistry models will be new to students. Studies have shown that these particulate nature of matter and models of atoms and molecules are difficult to learn (e.g. Harrison and Treagust 1996, 2002) as students do not encounter them in their daily lives and they involve abstract invisible sub-microscopic entities and their interactions (Carr 1984). During teacher education and professional development programmes, teachers are encouraged to take additional care in teaching these models, allowing students time to make sense of the models and test their understanding of them. Animations, illustrations, concrete models and analogy are resources available for teachers to help students visualise the particles. Inquiry activities, such as how to remove the odour quickly from a room in which perfume has been spilled, are suggested to allow students to grapple with the relevant particulate nature of matter concepts.

In addition to similar inquiry questions in primary science about the parts of a system or different systems interacting together to perform a function, an additional inquiry question that lower secondary students have to grapple with under the theme of Systems is how parts of a system can affect the function of other parts in the same system. Students learn about the transport system in plants and animals again, this time taking into account the processes of diffusion and osmosis in the transport of substances. Advanced concepts in the human digestive system such as the function of enzymes and the use of the products of digestion by the cells are also learning outcomes at this level. The importance of personal hygiene and proper food handling procedures in the prevention of food-borne diseases are included in the syllabus (Ministry of Education Singapore 2012c) and news reports of outbreaks of food-borne diseases are excellent starting points for discussions. Learning the human reproductive system in lower secondary involves understanding in greater detail the reproductive systems in males and females, fertilisation and combination of genetic material from the father and mother, puberty, birth control and sexually transmitted diseases. The social and moral issues of pre-marital sex and abortion are important and relevant to students' lives, and teachers use debates and drama to help students explore these socio-scientific issues.

The final theme in lower secondary science is Interactions and it focusses on the "interactions between and within systems" as well as the "interactions between physical phenomena and life processes" (Ministry of Education Singapore 2012c, p. 30). This builds upon the students' primary science knowledge of forces, the interactions between living things and their environment. In addition to forces, students encounter pressure, energy and work done, sound and heat energy in lower secondary science. Activities to promote student learning include investigating the damage that the heels of different shoes can inflict on different flooring, creating music by varying the depth of water in containers and blowing over or striking these containers, and determining the fastest way to cool a container of hot water. Students learn various chemical interactions such as combustion, neutralisation and thermal decomposition, write word equations and see demonstrations or carry out experiments to experience these interactions. They also discuss the importance of chemical reactions in daily life such as rusting, cooking, combustion of fuels, fermentation and decay. In the ecology part of Interactions, the student continues to learn about interactions within various ecosystems, the flow of energy and recycling of nutrients within the systems, the need to conserve resources and protect the environment, and examples of sustainable living practices. Field trips, as mentioned previously in the discussion on Diversity, are essential in helping students experience and understand these interactions.

9.7 Upper Secondary and Pre-university Science

Science is an elective subject at the upper secondary and pre-university levels, although the majority of students choose to study at least one science subject. Upper secondary students (age 15–17) can choose to study combined science subjects such as chemistry-physics, chemistry-biology, or biology-physics or single "pure" science subjects, namely biology, chemistry or physics. At the end of the final year of secondary education, students will sit for a national examination, the Singapore-Cambridge General Certificate of Education (Ordinary Level) Examinations. The science examinations include written as well as practical papers. For biology, chemistry and physics as single subjects, the practical examinations are school-based and assessed by the students' teachers, while combined science subjects have one-off practical examinations at the end of Secondary 4 or 5. Curricular time allocated to one upper secondary science subject ranges from three to four hours a week.

Pre-university education is the final phase in the national school system and students (age 17–20) at this level can choose to study science subjects as major subjects (Higher 2 level or abbreviated as H2) in the Singapore-Cambridge General Certificate of Education (Advanced Level) Examinations. Science as minor subjects (H1 level) are also offered to students who wish to study science as a contrasting subject (in contrast to majors in the humanities and social sciences). Chemistry as a major science subject is the most popular science subject in pre-university as it is a prerequisite for the undergraduate medical, chemical and biomedical engineering programmes in local universities. Students who are outstanding in science can also be offered advanced science courses (H3 level) such as modern physics, pharmaceutical chemistry or proteomics, or carry out a research project supervised by science or engineering faculty members of local universities. About five hours a week are allocated to one science subject in pre-university.

The aims of the science subjects in upper secondary and pre-university are to equip students with the scientific knowledge, skills and attitudes to "become confident citizens in a technological world, able to take or develop an informed interest in matters of scientific importance" (Singapore Examinations and Assessment Board 2013a, b), understand the limitations of science as well as its applicability in daily life, and be adequately prepared to study science or science-related courses at their next level of education. Inquiry activities do not feature as much in upper secondary and pre-university science classrooms as in primary and lower secondary science as more emphasis is placed on the third aim of preparing students for higher education. Furthermore, curriculum time is limited and much time is devoted to teaching the prescribed examination syllabuses (Singapore Examinations and Assessment Board 2013a, b) in preparation for the national examinations. However, students do laboratory investigations as an integral part of the curriculum, and have opportunities to do science projects and this will be discussed in the next section.

Thorough understanding of concepts is important for the examinations and this is generally achieved in school by allowing students to have experience with the concepts through experiments or demonstrations and by using concept analysis

(Herron 1996) to help students grapple with the critical and variable attributes of the concepts. For example, secondary students can do experiments and find out that acids have a pH value less than 7, turn red litmus blue, and react with bases and carbonates, but may still not be able to explain what exactly an acid is. Concept analysis of acids based on the Arrhenius model used in secondary chemistry will reveal that they are substances that ionise in water to form hydrogen ions, and it is these ions that give the acids the properties that they observe in the experiments. To link associated concepts together, concept mapping (Novak 1996) is carried out by students to obtain a big picture of the concepts involved, especially in the larger topic, acids, bases and salts. Teachers will also help students to understand and use the representations involved in the various science subject. In chemistry, students need to be able to use chemical symbols and equations effectively to describe and explain the interactions of particles at the sub-microscopic level, which gives rise to the phenomena that they see at the macroscopic level (Kozma et al. 2000). As ICT is used rather extensively in Singapore, animations and simulations are normally employed to allow students to visualise the particles and their interactions.

9.8 Cultivating Students' Interest and Talents in Science

Secondary and pre-university students who have the aptitude and interest in science are given opportunities to participate in programmes such as the Science Mentorship Programmes (Ministry of Education Singapore 2006) where they work on research projects guided by mentors in tertiary and research institutions such as Nanyang Technological University and the Defence Science and Technology Agency. Students work about three hours a week on their projects for seven months when schools are in session and two weeks full time during their mid-year vacation. When they complete their projects, they are expected to write a scientific paper to be presented at the annual Youth Science Conference. Those who have produced high quality work usually go on to participate in the Singapore Science and Engineering Fair or even represent Singapore at the prestigious Intel International Science and Engineering Fair (Science Centre Singapore 2009). Some schools are very well-equipped with science research facilities and have teachers with masters and doctoral degrees in science. These schools organise their own in-house science research programmes where teachers will mentor their own school students to do science research in the school laboratories and then present their research findings at a school-based science event day. In addition to research and science fairs, students can also participate in science-based competitions such as the national and international science Olympiads, be attached to industry to experience science-related work, and participate in talks and forums given by distinguished international scientists and Nobel Laureates.

Singapore has two specialised schools for science. The NUS High School of Mathematics and Science, which is affiliated to the National University of Singapore (NUS), was established in 2005 to provide a 6-year programme (combining secondary and pre-university education) to students with special talents in, and passion for, mathematics and science. The school awards its own diploma at the end of Year 6, unlike most other pre-university institutions which offer the Singapore-Cambridge General Certificate of Education (Advanced Level). It attracts the top 10 % of the national cohort of Primary 6 students (NUS High School n.d.). There are special programmes in the school such as the Da Vinci research programme with full time research attachment with scientist mentors, and the Einstein + programme which involves exceptional talented students taking university-level modules in NUS, being mentored by NUS professors and undergoing Olympiad training.

Another specialised school is the School of Science and Technology, which recruited its first batch of students in January 2010 (School of Science and Technology 2012b). The school partners with Nanyang Technology University and Ngee Ann Polytechnic to design its curriculum and enrichment programmes. It offers a 4-year programme that has an enriched curriculum focusing on applied learning that has stronger connection to applications in real-life contexts. Students sit for the Singapore-Cambridge General Certificate of Education Ordinary Level Examinations at the end of Year 4 but they are also able to select applied subjects such as biotechnology and fundamentals of electronics (School of Science and Technology 2012a). Innovation and entrepreneurship is strongly emphasised in the school and students attend courses providing the necessary knowledge and skills, fostering the requisite attitudes and habits of mind, and offering students opportunities to engage in “innovation and entrepreneurship in simulated and authentic contexts” (School of Science and Technology 2012c).

9.9 Science Education Research

Tan (2010) reviewed the state of science education research in Singapore from 1971 to 2008 and found that studies conducted before 1990 were focused mainly on local issues and were rarely published in international journals. She argued that research in science education in Singapore started to grow after the launch of policy initiatives by the Ministry of Education such as the use of ICT in schools and the development of students’ creativity and thinking skills. The establishment of the Centre of Research in Pedagogy and Practice by the National Institute of Education and the Ministry of Education in 2004 also played a large part in the progress of science education research as the provision of grants supported larger scale research, and publication in international journals was an important performance indicator for grant recipients. Studies conducted were researcher-driven, resulting in a diversity of research and publication in areas such as science teachers’ pedagogical content knowledge, classroom learning environment, ICT in science, inquiry-based learning, argumentation, scientific discourse, student understanding and alternative conceptions, and affective learning in science. While studies elsewhere have suggested that research appears to have limited influence on classroom practice and policy (Davies and Nutley 2008; Levin 2013; Nelson et al. 2009), studies have yet to be conducted to determine how the uniquely close relationship between the National Institute of Education, the Ministry of Education and schools influence the impact of science education research on classroom practices.

9.10 Future Directions

Singapore's education system is constantly evolving to help students take on challenges of the present and future, and the Singapore science curriculum moves in tandem with it. We are of the view that five recent developments will have a significant impact on science teaching and learning in Singapore for the next decade:

(a) Singapore's curriculum is reviewed about every 6 years. In the last two cycles of curricular review, there has been a strong emphasis to coherently develop themes and big ideas across the spiral curriculum. This will help teachers and students integrate and transcend scientific concepts and focus on "big ideas" of science and will be most impactful in applied fields of science. Our view, however, is that conspicuously missing in the science syllabuses are big ideas in earth and space science. While there are considerations of adequate curricular time to include earth and space science topics, it might be worthwhile for the curriculum specialists and science educators to examine whether this has resulted in fundamental knowledge gaps in today's context. After all, earth and space science concepts and big ideas such as the continuously changing planet, natural hazards, our dependence on resources from the earth, atmosphere and weather, and changes to the planet caused by human activities (American Geosciences Institute 2014; National Aeronautics and Space Administration 2011) are fundamental to understanding some of the most critical environmental and security issues plaguing nations today.

(b) Our view is that the inquiry-centric science syllabuses and suggested teaching and learning approaches are in the right direction to shift the focus of teachers from just teaching science as bodies of knowledge to also include teaching science as a way of thinking to make decisions in daily life, solve problems and create new ideas and products for the benefit of mankind. It also equips students with skills and dispositions that are useful beyond the realm of the science discipline, for example reasoning and problem-solving skills, and an inquiring mind that is open to alternative and novel ideas.

(c) The recent initiative on applied learning that go beyond textbook knowledge to real-life hands-on application of scientific principles would enrich the learning experiences of students and better equip them with relevant skills for the twenty-first century. To bring in an anecdotal example, a group of students saw very little relevance in learning chemical bonding as it was abstract to them. Their interest was, however, invoked when their science teacher demonstrated that the creases in his shirt was actually due to chemical bonding between the molecules of the shirt material which prevented parts of the material from unfolding. Shirts could thus be made more crease-resistant by modifying the interactions between the molecules in the material. This focus on how humans can harness scientific knowledge and technology to create solutions to problems they encounter in everyday life has the potential of developing minds that are flexible and ensuring that the general population is scientifically literate and able to thrive in the twenty-first century with its rapid scientific and technological advances, even if they do not study science or science-related disciplines at the tertiary level.

(d) Teacher development policies have been transformed in the last 15 years. Singapore has created three tracks for the teaching service (Ministry of Education Singapore 2014). In addition to the leadership track, Master Teachers of Science are appointed in the Teaching Track to develop innovations in teaching and learning pedagogies and take on mentoring roles across schools to spread the use of these new pedagogies. Senior Specialists on the Specialist Track are given training to develop expertise that are essential for breaking new grounds in curriculum and resource development. Professional development opportunities for teachers, including science teachers, have also been enhanced to help teachers grow professionally throughout their career, for example, through professional development leave and work attachment for teachers. In 2010, the Singapore Ministry of Education also set up the academies, which includes the Science Subject Chapters (Academy of Singapore Teachers 2012), to support more teacher-led professional development efforts.

(e) The accessibility, plausibility and feasibility of science education research (Tan and Gilbert 2014), conducted in Singapore and elsewhere, to teachers and policymakers are important considerations for research to have impact on practice and policy. Research findings have to be translated into forms which are easily available, understood and used by teachers and policymakers. Some encouraging trends which have emerged in recent years: (i) more teachers pursuing a degree in Masters of Education and hence, leading to an increase in the number of practitioners with knowledge about research and heightening of chances that research findings may be utilised in classroom practice; (ii) more science education faculty members being invited to schools to discuss research design, implementation and findings; and (iii) more researchers actively inviting policy makers and teachers to come on-board research projects as collaborators so that there is greater alignment between the research project goals and policy and practice.

Even as we are writing this chapter to describe what we know about science education in Singapore in the last 50 years, the new chapter of science education in Singapore is unfolding and as science educators in Singapore, we look forward to contributing to this new narrative.

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