Chapter 6
Science Education in Singapore

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Abstract As a young and small nation with little else other than human resource, education has played a crucial role in the economic survival, prosperity and progress of Singapore since her independence. Closely aligned with its overall education system, Singapore's science curriculum aims to help the young develop and realize their potential amidst a flexible, diverse and broad-based educational landscape. Centred on the theme of science as inquiry, the science curriculum, from primary to junior college/preuniversity levels, puts particular emphasis on the knowledge, skills and processes, and ethics and attitudes of science, as well as the understanding of the impact of science in daily life, society and the environment. In this chapter, we discuss the evolution of the science curriculum in Singapore as well as how it supports students in developing the scientific literacy, competencies and values necessary for them to take on challenges and thrive in an ever-changing world.

Keywords Singapore science education · Science curriculum · Education reform

6.1 Introduction

As a young and small nation with little else other than human resource, education has played a crucial role in the economic survival, prosperity and progress of Singapore since her independence. Closely aligned with its overall education system, Singapore's science curriculum aims to help the young develop and realize their potential amidst a flexible, diverse and broad-based educational landscape. Centred on the theme of science as inquiry, the science curriculum, from primary to

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junior college/preuniversity levels, puts particular emphasis on the knowledge, skills and processes, and ethics and attitudes of science, as well as the understanding of the impact of science in daily life, society and the environment. In this chapter, the evolution of the science curriculum in Singapore is described as well as how it supports students in developing the scientific literacy, competencies and values necessary for them to take on challenges and thrive in an ever-changing world.

6.2 History of Science Education in Singapore

The evolution of science education in Singapore can best be described in terms of the phases of education reform that the country has gone through since gaining her independence in 1965 – the survival-driven phase, efficiency-driven phase, ability-driven phase and student-centric, values-driven phase. Table 6.1 shows a summary of the four previous phases of education reform in Singapore and the science curriculum, as well as the current phase. (For readers interested in how the education phases influenced mathematics education, see Chap. 7.)

6.3 Survival-Driven Phase (1965–1978)

With little else but a thriving seaport industry and people as the only natural resource, after independence, Singapore's first concern was to survive amidst uncertain conditions. One of its immediate goals was to shift the economy from an entrepot trade to a focus on export-oriented industries and to attract multinational corporations to Singapore. Producing a 'literate and technically trained workforce' (Goh & Gopinathan, 2008), strong in mathematics, science and vocational skills, thus became the main focus of the education system at that time. In order to prepare a labour force with the skills required by the industry, the science curriculum during the survival phase emphasized knowledge acquisition and development of skills such as handling apparatus and materials and reasoning. Science teaching was mostly didactic in nature, with the occasional confirmatory type of experiments. The first government-administered national examination system, the Primary School Leaving Examination (PSLE), was established in Singapore in 1960, to unite the examinations conducted by the individual primary schools into one national examination.

Table 6.1 Phases of education reform in Singapore and her science curriculum

	Survival-driven phase (1965–1978)	Efficiency-driven phase (1979–1997)	Ability-driven phase (1997–2011)	Student-centric, values-driven phase (2011–2018)	Empowering individuals, nurturing the joy of learning (2018–present)
Impetus	Industrialization, economic survival	Economic competitiveness and high attrition rates in school	Knowledge-based economy and technological advances and globalization	To remain relevant to the needs of the society and economy	Disruption to industries and jobs brought about by technological advancement
Education purpose	To develop a literate and technically trained workforce	To enable each pupil to go as far as possible in order to achieve the best for training and employment	To maximize potential of each pupil and achieve maximal harnessing of talents and abilities	Holistic development of a child centred on values and character development	To develop a growth mindset and to take greater ownership of one's learning and lifelong development
Education focus	Bilingualism, mathematics, science and technology education, vocational training	Academic streaming	Thinking Schools, Learning Nation (1997) IT Masterplans (1997, 2002, 2008) Teach Less, Learn More (2004) Innovation & Enterprise (2004) 21st CC (2009)	Citizenship & Character Education (2010) Holistic education; student-centric, values-driven (2011) Applied learning (2013)	Joy of learning (2018) Subject-based banding (2019)
Focus of science education	Develop skills and capabilities needed for the industrialization process	Standardization of textbooks, workbooks and teaching guides	Inquiry learning	Inquiry and applied learning	Potentials and opportunities

6.4 Efficiency-Driven Phase: 1979–1997

The efficiency phase took over from the survival phase at the time when Singapore was beginning to reap the fruits of her efforts. The country had a low unemployment rate, an average growth rate of 10% and a booming manufacturing industry (Cahyadi, Kursten, Weiss, & Yang, 2004). However, the lower labour costs of neighbouring developing countries posed a real threat to the tight labour market and higher cost of operation in Singapore (Goh & Gopinathan, 2008). The Second Industrial Revolution in the 1980s brought about by technology advancement created new industries capitalizing on research and development, engineering design and innovation and computer software development (Yuen, 2008). Coupled with falling birth rates, all these impetuses meant that the country could no longer remain a highly labour-dependent economy, but needed to break into more technology- and capital-intensive industries (Goh & Gopinathan, 2008). The diversity in work opportunities that came with this focus meant that the previous one-size-fits-all education system was not able to sufficiently serve the needs of the research- and technology-intensive economy. Hence, a more differentiated system was adopted. As well, the high attrition rates in schools and low levels of English language competencies at that time meant an efficiency model was needed to ensure that the country's human resources were fully maximized. One of the key features of the efficiency model was academic streaming to allow students to progress at their own pace, as well as to enable students to progress as far and fast as possible academically (Chen, 2000). This meant that students who were more inclined in science were given the opportunities to specialize in the domains of science they were good at, while students who were more inclined in technical work were streamed into vocational institutions. At the primary (Grades 1–6) and lower secondary (Grades 7–8) levels, while a common science subject was offered to all students, its conceptual and cognitive demands were differentiated by streaming; those who were more academically capable will study the subject at a higher and more demanding level. At the upper secondary (equivalent of Grades 9 and 10) and junior college levels (equivalent of Grades 11 and 12), science was offered to the more academically capable students as single disciplines (biology, chemistry and physics), while others were offered a combination of two or three of these science disciplines at a less demanding level.

Standardization was the other hallmark of science education during the efficiency phase. For the first time, science textbooks, workbooks and teaching guides were published by the Ministry of Education, Singapore (MOE). Large numbers of teachers, including those with little science background, were trained to teach science using these resources, and content mastery and skills development continued to take centre stage. In 1995 Singapore took part in the Trends in International Mathematics and Science Study for the first time and emerged among the top-performing countries for Grades 4 and 8 (TIMSS International Study Center, 1996, 1997).

6.5 Ability-Driven Phase: 1997–2011

The ability-driven phase replaced the efficiency-driven phase as Singapore approached the twenty-first century. This was an exciting time when the myriad of changes to the education system, including the science education, were fuelled by the rapid globalization and technological advances happening in the 1990s. As new jobs appeared and old ones disappeared, there was a realization that learning could no longer be confined to the 10–16 years of formal education; the ability to learn independently throughout one's life, create knowledge, collaborate and think critically became coveted skills. To foster these twenty-first-century abilities along with a passion for lifelong learning, the focus of the MOE was to help students develop and harness their talents and abilities to the maximum (Tan, 2005). In place of standardized methods of teaching, innovative programmes and curricula, together with multiple pathways to maximize one's potential, were made available. Applied subjects were introduced in 2008 to the secondary school students and offered as examinable subjects at the General Certificate of Education Ordinary (GCE 'O') level to better cater to the interests and aspirations of students who were keen to progress along an applied and practice-oriented path of education. The GCE 'O' level examination, the national examination at the end of Grade 10, is administrated by the MOE and the Cambridge International Examinations.

In the science curriculum, 'science as inquiry' was introduced as an overarching framework for the science curricula (MOE, 2004) to nurture the inquiring minds needed for lifelong learning and to develop the creative, critical and collaborative skills needed in the knowledge-based economy. The inquiry framework identified the 'integral domains of (a) Knowledge, Understanding and Application, (b) Skills and Processes and (c) Ethics and Attitudes' (MOE, 2004 p. 1). Both the student and the teacher were involved in the inquiry process with the student as the inquirer who determined ways to solve problems by asking appropriate questions, planning and conducting experiments, analysing the data collected, drawing conclusions and communicating and defending their findings (Chinn & Malhotra, 2002). This curriculum positioned the teacher as the leader of the inquiry (MOE, 2004), 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. In alignment with the inquiry framework of the science curriculum, school-based practical assessment was introduced in 2006 to replace a one-time traditional practical examination at the end of the Grade 10. Instead, students were assessed in a series of practical sessions throughout the 2 years on skills sets such as performing and observing, analysing and planning. A similar practical examination format was applicable to the General Certificate of Education Advanced (GCE 'A') level for the sciences at the end of Grade 12. (For an in-depth discussion on inquiry as the pedagogical framework in the Singapore science curriculum, see Chap. 11. For an in-depth discussion on how teachers are prepared and continually developed professionally, see Chap. 14.)

During this period, alternative education pathways such as specialized schools and integrated programmes (IP) were introduced to provide opportunities for schools to experiment with more innovative instructional methods customized to the needs of their students (MOE, 2012a). Two specialized schools for mathematics, science and technology were established to develop those students who have particular talents and interest in the science. NUS (National University of Singapore) High School of Mathematics and Science was set up in 2005 to nurture well-rounded students with high aptitudes in science and mathematics through a 6-year diploma programme. The School of Science and Technology was set up in 2010 to nurture passionate innovators through the application of science, technology, engineering and mathematics (STEM). The IP, offered only to selected schools already in the education system, provided an integrated secondary (Grades 7 to 10) and preuniversity (Grades 11 to 12) education for secondary school students to proceed to preuniversity without taking the GCE 'O' Level Examinations at the end of Grade 10. The time freed up from preparing for the GCE 'O' Level Examinations allowed schools to experiment with different approaches of inquiry teaching and learning methods. During this time, science education research in Singapore was gaining ground. Partnerships among researchers and educators to develop inquiry pedagogies using technology were encouraged. Examples of such research partnerships include project that investigated problem-based learning approaches (e.g. Yeo & Tan, 2014), knowledge building (e.g. Tan & Yeo, 2014; Yeo & Lee, 2012), informal learning (e.g. Dairianathan & Subramaniam, 2011), students' conceptions (e.g. Chu & Treagust, 2014), science teacher education (e.g. Tan, Tan, & Wettasinghe, 2011) and use of interactive digital media (e.g. Chee & Tan, 2012).

The proliferation of technology in everyday and working life also meant that people needed to be comfortable to learn, live and work with technology. During this educational phase, three Information Technology Masterplans were introduced in 1997, 2002 and 2008, respectively (MOE, 2008a), firstly to equip schools with a technology infrastructure and then to promote ICTs as pedagogical and communicative tools. The development of ICT tools, such as multiplayer games, virtual reality and mobile technologies, was and is still strongly encouraged. Education labs (MOE, 2012b) and FutureSchools@Singapore (MOE, 2008b, 2009) have been established for this purpose. As for teaching resources, there was also greater devolution of textbook publication to commercial publishers to harness on the expertise and creativity of these educational publishers to provide schools with a wider variety of interesting and stimulating instructional materials for the new curriculum (MOE, 1998).

6.6 Student-Centric, Values-Driven Phase: 2011–2018

To further strengthen the ability-driven framework that guided the country through the initial years of the twenty-first century, Singapore's education system embarked on its student-centric, values-driven phase. The trigger was to ensure that the young remain relevant to the needs of the economy and the society. With more employers valuing workers' ability to work and communicate effectively with others regardless of race and nationality, it is paramount that the young learn to collaborate with one another (MOE, 2011). To maintain the fragile fabric of social harmony, the next generation will also need to develop a caring disposition and be committed to the collective future of the country. Thus the focus of this education phase is holistic development that goes beyond cognitive and skills development to include an emphasis on 'values and character development'.

The twenty-first-century competencies framework (MOE, 2014a) was introduced to define the thrust of education for the future and attributes needed for an individual to thrive and contribute to an ever-changing world where this includes the competencies of civic literacy, global awareness and cross-cultural skills, critical and inventive thinking and ICT skills (refer to Fig. 6.1).

In this curriculum, science education acts as a platform for students, not only to learn the basic concepts of science but also to nurture a curious mind, integrity, perseverance and care for one another and the environment through an inquiry approach. At the same time, Applied Learning Programmes (ALP) and Learning for Life Programmes have been introduced to help students apply thinking skills and knowledge across all subjects. These aim to provide 'real-life experiential learning to develop their character and values, cultivate positive attitudes, self-expression and strengthen their people skills' (MOE, 2013a). Related to the science curriculum is the STEM ALP, which provides opportunities for students to apply their knowledge and skills in science, mathematics and technology to solve real-world problems, hence deepening their competencies in scientific inquiry, reasoning and problem-solving, design thinking, computational thinking, data analysis and use of technology (MOE, 2014b). Examples of STEM ALP implemented in our local secondary schools include themes on health sciences and flight and aerospace. The 'science as inquiry' framework thus continues to be relevant for students to see the contribution of science to their lives, society and their environment as they develop and apply science content and skills to the solution of real-life problems.

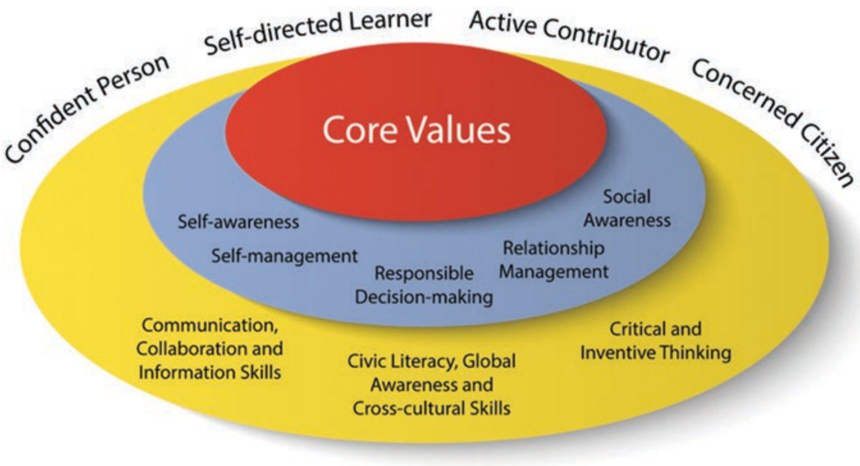

Fig. 6.1 Twenty-first-century competencies framework (MOE, 2014a)

6.7 Empowering Individuals, Nurturing the Joy of Learning Phase: 2018–Present

Disruptions brought about by technology have accelerated over the last few years, have displaced jobs and have changed the nature of industries. Skills upgrading and deepening are essential for Singaporeans to face the challenges of a fast-changing economy and a stronger demand for higher-skilled workers. Education can no longer be confined to the formal structures/years of education, but becomes a continuous effort towards attaining expertise and mastery of skills beyond their present competence. This cannot be driven merely by the current demands of their job, but a dedication towards excellence and passion in each area of strength and interest.

To align with this vision of a culture that supports and celebrates lifelong learning, changes are made at the K-12 formal structures. One is to remake pathways in education by offering greater flexibility with subject-based banding, in place of the academic streaming introduced in the early 1980s. This change will allow students to build on their strengths by taking subjects at a level suitable to their academic ability. In other words, a student stronger in sciences can opt to take the sciences subjects at a higher level even if his performance in other subjects are weaker. Besides addressing the unintended consequences of labelling and stigmatization associated with streaming (Davie, 2019), providing these flexible pathways to success can better encourage students to adopt a growth mindset (Heng, 2014), put in effort to develop their abilities and take greater ownership of their learning and lifelong development. Another major initiative that has been recently introduced is the inculcation of the joy of learning. To achieve this vision, efforts are made to move away from an overemphasis on academic results. The number of school-based assessments is reduced, and students' holistic development is heightened. For the science subjects, the school-based practical assessment conducted several times in a year has since been reverted back to a one-time assessment model, but with a stronger focus on the higher-order inquiry skills such as planning, analysing, concluding and evaluating. The time formerly spent on preparing students for multiple examinations and tests can now be used to engage them in activities that can better develop the joy for learning.

With this recent bold move to change the face of education in Singapore, we are starting to see other significant changes made to the science curriculum. Building on the inquiry framework that has anchored the science curriculum for the last decade, the revised curriculum goes beyond the acquisition of scientific knowledge and foregrounds the ways of knowing and doing science. Such a move recognizes the practices of science as more enduring in the quest for lifelong learning. With a less emphasis on testing, there are also greater opportunities for informal learning. The STEM ALP programme has expanded to include many more current and exciting areas including engineering and robotics, environmental science and sustainable living, food science and technology, health science and healthcare technology, ICT and programming, material science, simulations and modelling and transport and communication. Since 2018, all secondary schools offer ALP subjects to their students (MOE, 2018). It is targeted for all primary schools to embark on ALP by 2023 (Ng, 2018) to provide more science learning opportunities for the younger students as well.

6.8 Promising Future Directions in Science Education

Over the years, the science education system in Singapore has shifted from a simple mission of preparing her people to survive in a challenging world to ensuring that they can thrive in a complex and ever-changing one. Thus far, it has managed to achieve its goals. We attribute three factors which we believe are key in constructing a successful science education in Singapore: (1) the responsiveness and adaptability of policy makers and teachers, (2) fidelity of implementation and (3) partnership with industry and higher education institutions.

6.8.1 Responsiveness and Adaptability

For the science education system to remain relevant, there need to be mechanisms that ensure timely and appropriate actions are taken to respond to changes taking place in the economy and education. In Singapore, a group of science curriculum specialists and officers at the MOE regularly charts the direction of science education and designs the curriculum. Having a dedicated group of science curriculum specialists ensures that people who are well-equipped with knowledge and skills of curriculum matters, as well as a keen awareness of the global trends of science education, steer Singapore science education in the right direction. An annual workplan seminar, whereby the Minister of Education presents the direction of education for the year to a general education audience, ensures that teachers are informed of the policies rolled out so that timely action can be taken in the charted direction.

Another mechanism is the frequency of syllabus reviews. The science syllabuses are reviewed every 5 years, with an interim review every 2.5 years. This periodic revisit of the syllabus ensures responsiveness to economic, societal and other changes. The syllabus review committee usually consists of curriculum specialists, teachers, teacher-educators and higher education partners who take into consideration the needs of students, teachers and society. In view of the volatility of the economy and the rapid changes in the society, perhaps the involvement of industry partners could further align the science curriculum to the needs of the country.

As the curriculum changes, mechanisms are needed to ensure that teachers can respond and adapt to these changes. Instead of centralized training that was characteristic of the efficiency-driven phase, peer-based forums among clusters of schools within close proximity, as well as professional learning communities among teachers within a school, are set up to promote the efficient sharing of effective teaching and learning practices among schools and teachers (Mourshed, Chijioke, & Barber, 2010); these are elaborated in the next section. Teachers can also choose in-service courses that suit their needs and interests within the 100 training hours per year that each teacher is entitled to. In this way, teachers' professional development needs are adequately and readily addressed.

6.8.2 Fidelity of Implementation

When a syllabus is revised or changes in curriculum are introduced, it is necessary to ensure that the curriculum is implemented as intended (Lee, 2013). Support in terms of hard and soft infrastructure are provided to support the implementation of the changes. Hard infrastructure refers to the hardware needed. For example, when the IT Masterplan I was first introduced into the system, the first task was to introduce the necessary hardware that could support science inquiry, and so schools were equipped with data loggers to ensure that inquiry with technology was possible (Ng, 2008).

The other factor that can affect the fidelity of implementation is the science teachers. In this case, the soft infrastructure refers to continuing professional development needed to prepare teachers to implement changes in curricula in their classrooms. They need to understand the rationale of the curriculum and to be able to carry out learning activities that can best achieve curriculum knowledge, skills and attitudinal objectives. Professional development plays an important role to ensure that the curriculum is implemented as designed (Ng, 2009). For example, teachers need to be equipped with the appropriate skills (e.g. facilitation, dialogic skills) to carry out inquiry activities with their students. To this end, teachers are supported at different levels – the community level, the school level and the individual level. At the community level, schools within the same area come together to share best practices and innovation with one another. They can even plan and share lessons with one another. At the school level, teachers, especially beginning teachers, are mentored by senior teachers who have been shown to have excellent pedagogical practices and have been specially appointed to support less experienced teachers to enact the science curricular aims. Professional learning communities (PLCs) within a school also encourage and support teachers to collaborate with one other to conduct critical inquiry on their practices (Ng, 2009). To this end, practical-based research courses such as lesson study, learning study, learning circle and video-based critical inquiry help to equip teachers with the know-how so that they can better evaluate how their practices are aligned with the directions of the new curricula (MOE, 2012c). The participation in teacher-led research is evident by the significant number of presentations made by teachers at both local (e.g. Singapore Teachers' Conference) and international conferences (e.g. International Science Education Conference, 2014, 2018).

At the individual level, there are many courses and programmes that in-service teachers can pursue to keep themselves abreast with new pedagogy, to upgrade their content knowledge and to develop new teaching and ICT skills in order to implement the curricular initiatives (Bautista, Wong, & Gopinathan, 2015). These are primarily offered by the Academy of Singapore Teachers (AST) and the National Institute of Education, Singapore. The AST is the professional development arm of the MOE. Organized into various subject chapters/learning centres by discipline and learning profile of students, each subject chapter/learning centre offers workshops to teachers through their Networked Learning Communities (NLC). On the other hand, NIE is an institution of the Nanyang Technological University, Singapore, that works closely with the Curriculum Planning and Development Division (CPDD) and AST in MOE to identify areas of teacher professional development needed to realize the vision of MOE. As a higher education institution, it is able to offer in-service and higher-degree courses and programmes that lead to certification. Many of these courses and programmes are fully sponsored by either the MOE or the school to encourage teachers to upgrade themselves.

6.8.3 Industry and Research Partnerships

To help teachers and students better keep in touch with the world outside the confines of the classroom, industrial partnership is encouraged. The teacher work attachment programme (TWA) encourages teachers to take up work attachments in external organizations to broaden their outlook of the kinds of industrial skills needed by the economy and to experience life in these organizations (Shanmygaratnam, 2004). With the experience and knowledge gained from these work attachments, teachers are able to advise their students on career choices, the importance of the skills, concepts and values that they are learning and how these are applied in the workplace. For students, work-shadowing/attachments and/or visits to science-related companies are also encouraged, with the intent of giving them a taste of life outside the familiar confines of the school compound and helping them make more informed career choices (MOE, 2013b).

In recent years, research partnerships between schools and science education researchers have been encouraged. With a growing culture of education research among teachers, there is also a greater collaboration among schools and science education researchers to look for new ways of teaching science and/or to better understand how students learn science. Examples of this research can be found in http://www.nie.edu.sg/office-education-research/education-research-projects. Such research partnerships help to ensure that improved and innovative ways of teaching are well grounded in the contexts of implementation as the frontiers of teaching and education are being explored.

6.9 Conclusion

Science and technology has always been the foundation of Singapore's progress (Teo, 2015). This is evident in the growing diversity of STEM-related industries as well as the increasing presence of global corporations and local start-ups. The medical technology industry, for example, which includes large MNCs and local start-ups, contributed S$ 4.3 billion in output in 2011 (Economic Development Board, 2014). As the country forges its way into the science and technology-driven future, much STEM expertise is needed. The science education system will continually evolve to address the needs of society and the economy and continue to be the cornerstone in the building of the nation.

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