Chapter 3
STEM Education in Singapore

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Abstract Singapore students' outstanding performance in international benchmark tests such as PISA and TIMSS has attracted attention from all sectors of education. The PISA and TIMSS mathematics and science results have been extrapolated to imply successful STEM education as these two disciplines are core subjects in most school systems around the world. However, the local and international STEM community remains divided in our understanding of STEM and STEM education. In this chapter, we shed some insights on our understanding of this acronym and provide an overview of STEM education in Singapore. Based upon our understanding of STEM, we show how we have used it to inform our work at our STEM education research centre, the *Multi-centric Education Research and Industry STEM Centre* at the National Institute of Education (meriSTEM@NIE). We also describe the work of the Science Centre Singapore and the Ministry of Education in catalyzing STEM education in secondary schools. Last, we describe two specialized, independent schools in Singapore that are similar to the elite, specialized STEM schools in the United States. In the final section of this chapter, we raise four key issues and challenges which STEM education stakeholders have to confront as STEM education in Singapore continually takes shape and form.

Keywords STEM education · Singapore · meriSTEM@NIE · STEM Inc.

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3.1 PISA and TIMSS: Strong Foundations and Rising Challenges

Singapore's outstanding performance in Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) (OECD, 2019a; Teng, 2016) has attracted attention from all sectors of education (policy-making, teaching and research) to try and understand "what works?" in the Singapore education system. The areas of interest include policies and practices that result in the excellent and consistent outcomes across the measured domains. Specifically, Singapore's 15-year-old students topped the mathematics, science and reading PISA 2015 tests. To quote an Organisation for Economic Co-operation and Development (OECD, 2019b) comment about top performers,

> Top-performing students in science can use abstract scientific ideas or concepts to explain unfamiliar and more complex phenomena and events. In mathematics, they are capable of advanced mathematical thinking and reasoning. In reading, top performers can retrieve information that requires the student to locate and organise several pieces of deeply embedded information from a text or graph.

Not only did Singapore students score well in the subjects, they also topped the Collaborative Problem-solving portion of PISA 2015, meaning that they could work in teams to solve problems (OECD, 2017). This suggests the success of the Ministry of Education (MOE) focus on developing twenty-first century competencies (MOE, 2018a), beyond improving the quality of mathematics and science education in Singapore.

Against an international backdrop where "the jobs of the future are STEM [acronym for science, technology, engineering, and mathematics) jobs" (National Science and Technology Council, 2013, p. vi), there is a growing urgency in many countries, including Singapore, to develop their STEM capabilities amidst perceived and actual needs to fill current and future STEM jobs (see e.g., Lee, 2015; U.S. Department of Education, n.d.). Singapore's excellent performance in PISA and TIMSS have been extrapolated to imply successful STEM education as these two disciplines are amongst the core subjects in STEM education. Therefore, the success of Singapore's mathematics and science education has stirred up interest among international policy makers, educators and researchers to find out how Singapore pursues its STEM ambitions.

However, STEM education in Singapore is still emerging and evolving. Internationally, STEM education is a nebulous concept as there is no consensus on the definition of "STEM" (Holmlund, Lesseig & Slavit, 2018). As Jonathan Gerlach (2012), an American teacher who was awarded the Albert Einstein Distinguished Educator award said,

> "Everybody who thinks they know what it means, knows what it means within their field, and everybody else is defining it to fit their own needs." I think it is truly impossible to define STEM because it means so much for so many different groups of people. Whether it is researchers, science and mathematics teachers, the aerospace industry, or the construction

> industry, they all have one thing in common: It is about moving forward, solving problems, learning, and pushing innovation to the next level.

While we agree that it is very challenging to come up with a definition of "STEM", it is important for people to state upfront how they understand "STEM" to qualify their recommendations and claims.

As the Co-Heads of the first STEM education research centre called the *Multi-centric Education Research and Industry STEM Centre* at the National Institute of Education (meriSTEM@NIE) set up in Singapore, we will focus more on how our work is informed by what we think is considered "STEM". To some individuals, any work in the field of S, T, E, or M may be classified as STEM-related; to others, some degree of explicit integration is necessary. We lean towards the latter class of definitions. Riley (2014), for example, have described STEM as "the intentional connection between two or more of these [STEM] selected content areas to drive instruction through observation, inquiry, and problem solving as an approach to teaching and learning" (p. 19). Tsupros, Kohler and Hallinen (2009) has described STEM education as follow:

> [STEM education] is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real world lessons as students apply science, technology, engineering and mathematics in contents that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy.

Certainly, the term "intentional" is crucial to STEM education as many existing lessons labelled as "STEM" are activity-driven rather than disciplinary-driven. For example, students may be excited about a robotics activity because they have learnt how to write codes to control a car. However, students may not value the disciplinarity of the STEM disciplines integrated in the activity if they do not appreciate how purposeful connections of the STEM disciplinary knowledge and practices have afforded the observed outcomes. Clearly, there is a vast difference in the quality of students' learning experience in simply having fun and invoking what we call, *disciplinarity-valuing*. In another paper (Tan, Teo, Choy, & Ong, 2019), we have discussed at length how various scholars, including Becher (1989), King and Brownell (1966a, b) and Toulmin (1972a, b) have theorized about the construct "discipline". Our purpose was to underscore the importance of understanding the nuances of different disciplines in terms of the conceptual, epistemic, and social affordances and constraints (Kelly & Licona, 2018). With this knowledge, teachers can then design and enact meaningful curriculum that help students to appreciate the value of STEM integration. The balancing act of horizontal integration for deepening and vertical integration for broadening knowledge and practices has to be carefully orchestrated in the school curriculum to meet diverse education outcomes.

As academics, teacher practitoners and policy makers continue to seek clarity on what is "STEM", we aim to offer some broad and specific insights to the fast-changing STEM education landscape in Singapore and to highlight the ground-up initiatives and the support provided by MOE to drive STEM education across K-20 education sectors. In what follow, we provide snapshots of what is happening in the

STEM education landscape in Singapore. Last but not least, we will point to the key challenges and issues in STEM education and suggest how future research may provide new insights into the design and implementation of STEM education in Singapore, and possibly beyond.

3.2 The STEM Education Landscape in Singapore

Learning about STEM education has gained traction in Singapore, as well as worldwide, as cross-disciplinary (as opposed to mono-disciplinary) knowledge and skills are valued in modern times to meet the demands of the fourth industrial revolution (Penprase, 2018). The advent of the fourth industrial revolution places importance on digitization and technology on human life and communities. Their impact on and transformation of the lives of ordinary people have never been more significant. Responding to the potential impact of the STEM economy, our Singapore leaders have voiced the importance of STEM education. In his keynote at *ASEAN@50: In Retrospect Seminar* in 2017, Emeritus Senior Minister Goh Chok Tong (Yong, 2017) said, "We must push bright young students towards STEM." Former Minister of Education, Mr. Heng Swee Keat (2017) have also said, "STEM education centres on ideas, inquiry, and innovation. These are instrumental to life and can be applied to many other fields." According to Prime Minister Lee Hsien Long, developing STEM capabilities have been identified as necessary to maintain Singapore's economic growth (Lee, 2015). Given that there is a lack of natural resource in Singapore, STEM education is responsible for providing Singapore with three forms of intellectual capital:

- STEM experts (e.g., scientists, engineers) who will do research and develop STEM products central to the economic growth and national security of Singapore.
- STEM proficient workers who are capable of dealing with the demands of the STEM-based workplace.
- STEM-literate citizens who can make informed decisions about public policies and understand the world around them and their families.

Yet, despite the overwhelming outputs of STEM knowledge and artefacts, the abilities of our educators and young people to take advantage of these new opportunities remain diffused (Koh, 2018). There is, therefore, a need for concerted and deliberate effort by STEM researchers to be involved in more cross-disciplinary education research, so as to understand how innovators and entrepreneurs can "marry technology with design, psychology and sociology" (Koh, 2018). With increasing global trends of reliance on STEM achievements and advancement in the twenty-first century workforce, Singapore needs to ensure that STEM education is infused into our education system effectively to prepare a future-ready workforce.

Although there is no explicit STEM curriculum framework at this point in writing, there has been systemic support from the Ministry of Education (Singapore) to promote STEM education through funding several STEM initiatives: STEM Inc., STEM Applied Learning Programmes, two STEM-focused schools, and from numerous ground-up effort from schools offering STEM co-curricular activities, competitions, and research projects. In addition, the meriSTEM@NIE Centre at NIE has also played a key role in driving STEM education research, teaching and outreach.

To scope this paper, we will focus on the following and for the respective reasons:

1. **meriSTEM@NIE**: It is the only STEM education research centre in Singapore focusing on STEM education research, teaching and outreach.
2. **STEM Inc. and MOE STEM Applied Learning Programme (ALP)**: STEM ALP has been widely adopted by primary and secondary schools in Singapore. STEM Inc., an entity of the Science Centre Singapore, is established to support schools in the implementation.
3. **STEM-focused schools for gifted and talented students**: There are four specialized independent schools in Singapore (MOE, 2017) catered to talented students with specific interests in sports, the arts, mathematics and science, and applied learning. Two of these schools specifically cater to students who are gifted and/or talented in the sciences and/or mathematics and are similar to specialized STEM schools in the United States (Thomas & Williams, 2009).

3.2.1 meriSTEM@NIE

Located within the Nanyang Technological University and leading teacher education institute, the National Institute of Education, meriSTEM@NIE is well-positioned to harness the strengths of STEM and STEM education experts in Singapore. meriSTEM@NIE is an aspiring powerhouse of local and international scientists, technologists, engineers, mathematicians and educationists, responsible for bridging pure STEM disciplines and education research for the purpose of promoting the translation and scalability of STEM research outputs to K-20 (kindergarten to graduate) education contexts. The mission of meriSTEM@NIE is:

> [T]o enhance the quality of STEM literacy in Singapore through cross-disciplinary partnerships in research, teaching, and outreach so that future generations of educators, learners, and citizens are able to harness relevant STEM knowledge and skills in addressing current and emerging challenges for self and others.

Research, teaching and outreach form the three key pillars of our work. As a research centre within a teacher education institution, we ground our work in empirical knowledge drawn from research, build upon and extend the work of the STEM scholarly community and apply them in our teaching practices so that these are evidenced-based. We believe that partnerships with other organizations or entities with vested interest in STEM is important in order to create impact on teachers' and students' learning. Hence, we perform local and international outreach work in sharing our vision and approach to STEM curriculum making.

At meriSTEM@NIE, we adopt the working definition of STEM education as follow:

STEM education is a cross-disciplinary platform for learning disciplinary knowledge, practices, and dispositions of science, technology, engineering, and mathematics in integrative ways through the process of inquiring into real world problems and searching for improved outcomes.

The term "cross-disciplinary" is intentionally chosen to encapsulate the different forms of integration—namely, multi-, inter- and trans-disciplinary (Choi & Pak, 2006). According to Vasquez (2014/15), multi-disciplinary, inter-disciplinary, and trans-disciplinary forms of learning depict the different degree of connections between the separate disciplines. While disciplinary integration entails the separate disciplines, multi-disciplinary involves thematic learning but the concepts and skills are learnt separately. Inter-disciplinary work emphasizes on the integration of concepts and skills from two or more disciplines. Trans-disciplinary work blurs the boundaries between the disciplines as the focus is on the problem at hand. To make learning meaningful, it is always important to anchor the problem or issue for students to tackle within a real-world context (King & Ritchie, 2011). One of the purposes of STEM education is to fill a gap that traditional disciplinary education cannot offer, that is, to support students in making connections across the artificial disciplinary boundaries so as to better prepare them for the demands of the era of the fourth industrial revolution characterized by the convergence of digital, biological and physical innovations (Schwab, 2016). This definition has served as a guidepost in the design of an integrated STEM instructional framework, called the STEM Quartet (Tan, Teo, Choy, & Ong, 2019).

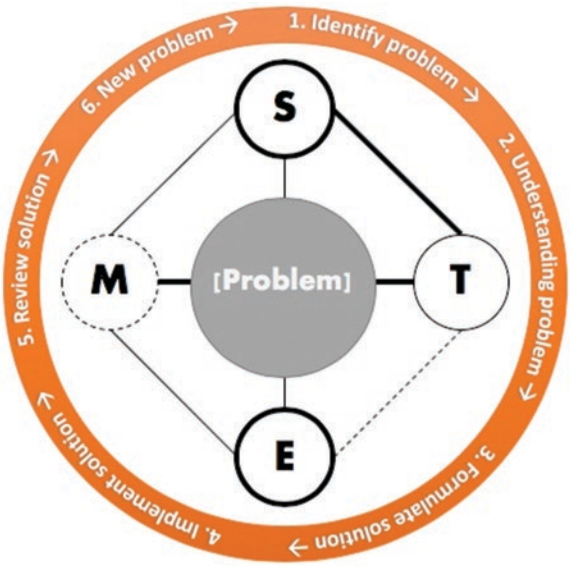
3.2.1.1 Research-Informed Curriculum Work at meriSTEM@NIE

In our paper entitled the *S-T-E-M Quartet* (Tan, Teo, Choy, & Ong, 2019), we have discussed how meriSTEM@NIE conceptualize integration in STEM. Different from other conceptual frameworks (see e.g., Banks & Barlex, 2014, Kelly & Knowles, 2016; Moore, Johnson, Peters-Burton, & Guzey, 2016), the S-T-E-M Quartet underscores the explicit vertical connections within the disciplines and horizontal connections between the disciplines. Figure 3.1 shows the S-T-E-M Quartet instructional framework anchored by a "problem" that has three characteristics, namely, persistence, complex and extended (Bereiter, 1992).

The recurrent nature of the problem—that has wide implications or impact on many different individuals or groups and that cannot be easily addressed using one discipline—is something that we look for in anchoring the STEM curriculum. The degree and number of disciplines that have strong connections may differ depending on the amount of conceptual knowledge, and epistemic practices and skills engaged in the problem-solving process (refer to the outer circle in Fig. 3.1).

To provide an example for illustration, Fig. 3.2 shows an example of a STEM activity which we have mapped out using the S-T-E-M Quartet as a guide. The "problem" resides in the real-world context to offer an authentic experience for students so that they find it meaningful to engage in the activity. In this instance, the

Fig. 3.1 The S-T-E-M Quartet instructional framework developed by meriSTEM@NIE. (Picture taken from Tan, Teo, Choy & Ong, 2019)



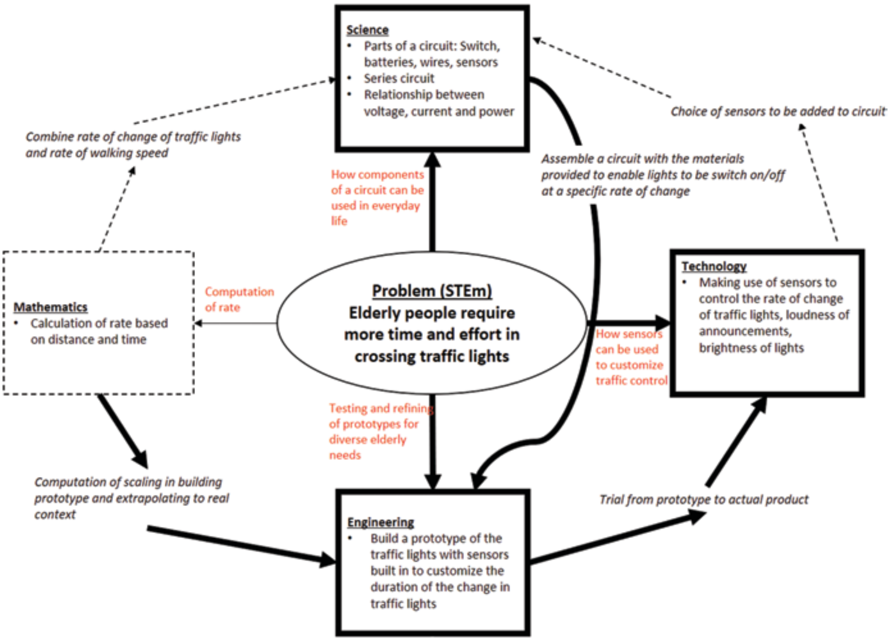


Fig. 3.2 An integrated STEM activity anchored in an authentic problem facing Singapore and many places in the world

problem of an aging population is real to Singapore and many other parts of the world including Japan, Italy, Portugal, Germany, Finland and the United Kingdom (Haider, 2017). According to the United Nations (n.d.), "Globally, the number of persons aged 80 or over is projected to triple by 2050, from 137 million in 2017 to 425 million in 2050. By 2100 it is expected to increase to 909 million, nearly seven times its value in 2017." Singapore is also feeling the impact of the rapidly ageing population. Singapore Prime Minister, Mr. Lee Hsien Loong, has raised concerns about the rise in the "sandwiched" families supporting the younger and elderly dependents, and increased demand for healthcare and social services (Ng, 2019). In the United States, the village movement has resulted in the forming of aging villages, due to the large numbers of elderly in one district, for the elderly to age gracefully in their own homes rather than to be relocated (Mercer, 2010). However, one problem often faced by the elderly is that the communities are not conducive to aging.

As such, the STEM problem is to get students to think about the control of traffic lights in an area with high elderly population. They may conduct research about some existing solutions (e.g., the Singapore Land Transport Authority Green Man + scheme [LTA, 2013]) and critique them. Then, they can think of other novel solutions such as adopting IoT (internet of things)-enabled sensors to adapt according to the needs of the elderly and ambient conditions (e.g., increased loudness of beeping for elderly who have hearing problems). Students can design and build prototypes of the traffic controls and test out how well their solutions work. Besides engineering and technology, some science knowledge and skills in building the circuits would be needed. While there is strong emphasis on S, T and E, some mathematics (small "m" to depict less mathematics emphasis) may be involved in performing some calculations on the rate of walking and the rate of change of traffic lights in order to not cause traffic congestion.

We have conducted several inservice courses for teachers in Singapore and elsewhere to teach teachers how to use the S-T-E-M Quartet to design, enact and evaluate STEM lessons. Figure 3.3 shows a photograph of a STEM lesson being mapped onto the S-T-E-M Quartet by a group of teachers from Hong Kong. After observing a STEM lesson in a Singapore school, they tried to identify the S, T, E and M and connections between the disciplines. Following this (not captured in the photograph in Fig. 3.3), they identified how the conceptual, epistemic and social goals of education (Kelly & Licona, 2018) have been addressed in the various parts of the lesson associated with the S, T, E or M.

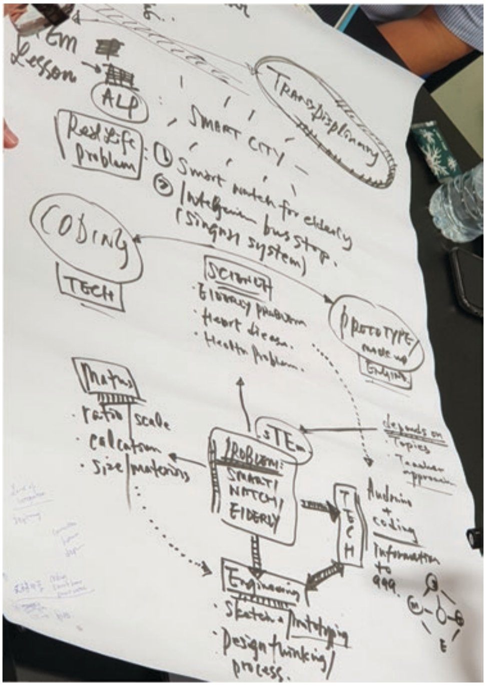


Fig. 3.3 Using the S-T-E-M Quartet to unpack a STEM lesson

3.2.2 STEM Inc. and MOE STEM Applied Learning Programme (ALP)

STEM Inc. is the acronym for Science, Technology, Engineering and Mathematics Innovation and Creativity, or Incorporation. It was established in 2014 as a unit of the Science Centre Singapore tasked to ignite students' passion in STEM and receives direct funding from the MOE. The main mandate of STEM Inc. is to support Singapore secondary schools in implementing the MOE STEM Applied Learning Programme (ALP):

> Applied Learning refers to an approach that emphasizes authentic and practice-oriented learning experiences, and is not necessarily restricted to vocational or technical education. It gives students additional opportunities to acquire skills and qualities based on the practical application of knowledge in real-world contexts, and strongly supports our focus on developing twenty-first century competencies and values in our students. (MOE, n.d.)

Applied Learning in schools is characterized by these features:

- Emphasizes the relevance of what is being learnt to current needs and future trends of industries;
- Provides hands-on or experiential learning for students to enact authentic scenarios;
- Equips students with the skills to engage in the practical application of knowledge; and.

- Could involve partnering the industry, community, institutions of higher learning, and/or professional training bodies."

MOE schools that embarked on the ALP will receive funding from the MOE to implement its programme. Schools can choose to focus on STEM, languages, humanities, business and entrepreneurship, aesthetics and interdisciplinary ALP. To date, there are more than 50 secondary schools who have embarked on the STEM-related ALP such as applied science, engineering and robotics, environmental science and sustainable living, food science and technology, health science and health care technology, info communications technology (ICT) and programming, material science, simulations and modelling, and transport and communication (MOE, n.d.). The curriculum in the ALP lessons are non-examinable. Students who have interest in and aptitude for specific fields of applied study can pursue STEM-related Applied Subjects such as Electronics and Mobile Robotics as an examinable subject in the upper secondary (Grades 9–10, aged 15–16) levels (MOE, 2018b).

For secondary schools, STEM Inc. has played a key role in the implementation of STEM ALP. The following information about STEM Inc. objectives are taken from the website (STEM Inc., 2018):

- To ignite students' passion for Science, Technology, Engineering and Mathematics (STEM) so as to inspire them to take up STEM-related courses.
- To raise students' aspirations in pursuing STEM careers by exposing them to the real-world industries.
- To uplift professional STEM career images.

STEM Inc. adopts the mindset and approach of the maker culture in its STEM curriculum making. This entails drawing inspiration from open sources, learning through doing, troubleshooting, receiving instant gratification, collaborating and experimenting (Tan, 2019). To date, STEM Inc. has created many curriculum packages which schools can select for their STEM ALP lessons. These topics include embedded electronics, engineering design and modeling, robotics, food science and technology, alternative energy, urban design and innovation, material science, flight and aerospace, and game design and simulation.

STEM Inc. and the MOE work in close partnership to support schools in their initial years of STEM ALP implementation. When a school embarks on STEM ALP and engages the help of STEM Inc., an officer from MOE and a Curriculum Specialist from STEM Inc. would offer consultations and customize lesson packages to meet the schools' and students' needs. A STEM Educator from STEM Inc. would be assigned to a school for a period of 3 years to develop, implement, revise, and finally hand over the STEM ALP curriculum to the school. During this time, the school teachers may preview, undergo professional development and co-teach the STEM lessons with the STEM Educator to gain experience in STEM curriculum making. In addition to curricular support, STEM Inc. also facilitate partnerships between schools and the industries through the STEM Industrial Partnership Programme for STEM professionals to volunteer as student project mentors. STEM Inc. runs teachers' professional development, sets up the STEM Communities of

Practice for networking and sharing, and organizes competitions for students (STEM Inc., n.d.). Such a model of partnership and continuing support allows for sustainability in STEM education efforts.

3.2.3 STEM-Focused Schools for Gifted and Talented Students

In a report (Rapporteur, 2011) provided by the U.S. National Research Foundation, Committee on Highly Successful Schools or Programs for K-12 STEM Education, four types of STEM schools in the U.S. were identified: selective schools, inclusive STEM-focused schools, STEM-focused career and technical education, and non-STEM-focused schools that offer STEM programmes.

Elite or selective STEM schools, such as the Illinois Mathematics and Science Academy, are STEM-focused schools designed for students who are highly-motivated and competent students interested in postsecondary and STEM careers. Through an advanced STEM coursework, highly qualified expert STEM teachers provide opportunities for students to engage in STEM-related independent research. STEM-focused career and technical education schools, on the other hand, prepare students for a broad range of STEM careers or engage students who are at-risk of school dropout. Inclusive STEM-focused schools are magnet schools that cater specifically to the underrepresented student groups so that they may pursue college education and careers in STEM. Some non-STEM-focused schools also offer STEM programmes for their students who have interest and are competent in these disciplines.

With the exception of the inclusive STEM-focuses, similar programmes to the other three types of schools or programmes can be found in Singapore. In particular, we will focus on the elite specialized STEM schools in Singapore. Even though the schools are not described as "STEM schools", they have similar programmes and share similar student demographics as some of the elite specialized STEM schools in the United States.

The National University High School of Mathematics and Science (NUS High) NUS High was established in 2005 with a founding principal, Associate Professor Lai Yee Hing, who was a faculty member in the Department of Chemistry at NUS. NUS High is an independent, specialized co-educational school offering a six-year (Grades 7–12, aged 13–18) curriculum which culminates in a NUS High Diploma (NUS High, 2019). The Diploma is recognized by local and top overseas universities. Although its curriculum niche is in STEM domains, the school also offers non-STEM subjects to offer students a rich and broad-based curricular experience. NUS High shares the common features of U.S. elite specialized STEM schools.

First, it offers advanced STEM coursework for students. Year 1–2 are the foundation years during which students will build strong foundations in the subjects. Year 3–4 are the advancement years where they will advance their knowledge and apply them. Year 5–6 are the specialization years where they will engage in advanced courses in their subject majors. Students are required to complete core, elective, enrichment, and honours modules as coursework; only core modules are compulsory. According to the Programme of Studies book (NUS High, 2018, p. 4) for students, "Honours modules are advanced modules designed at university undergraduate level for students specifically reading Mathematics or Science subject at Major with Honours level."

Second, besides mathematics and statistics, computing studies, biology, chemistry, physics, english language and literature, languages, humanities, music and art, the NUS High Da Vinci programme is a keystone programme that complements the subject-specific curriculum. The aim of this six-year programme is to develop students' multi-disciplinary and inter-disciplinary knowledge and skills in research, innovation and enterprise in multiple disciplines. In the first 4 years, they undergo a structured programme. This helps to prepare them to carry out independent research in Year 5–6 under the supervision of their teachers or with mentors at the university-based or national research laboratories. The students will then present their work at the NUS High School Research Congress or other local and overseas conferences. Such experiences help students to build up their communication and thinking skills needed in research and innovation work.

Third, NUS High has highly qualified teachers, many of whom have a Masters or Doctorate degree. As NUS High School is an independent school, it has autonomy in the hiring of teachers, including those without a teaching qualification but has relevant experience needed to deliver the school curriculum.

The School of Science and Technology (SST) SST is also one of the four specialized independent school in Singapore (SST, 2021). Established just 5 years after NUS High, SST offers a 4-year (Grades 7–10, aged 13–16) niche-programme in applied learning so that students gain strong foundation in STEM. At the end of the 4 years, students will sit for the national examinations. Besides the academic subjects, SST also leverage widely on ICT as it is one of the six schools on the FutureSchools@Singapore programme (MOE, 2015), which are supported by MOE to push frontiers in teaching and learning by harnessing ICT school-wide to effectively engage students in learning. The programme in SST is categorized as general curriculum, applied subjects, and extended curriculum. The general curriculum includes the languages, science, mathematics, integrated humanities, and sports and wellness. For applied subjects, SST offers biotechnology, computing, and design studies and electronics to cater to different interests of their students.

A key component of the extended curriculum is the ChangeMakers Programme, which aims to provide students with an integrated learning experience towards developing the attitudes and attributes of an innovator with an entrepreneurial mind. The programme integrates principles, knowledge and skills from the following areas:

- Art, Design, Media, and Technology;
- Innovation and Entrepreneurship;

- Information and Communication Technology;
- Mathematics; and.
- Science.

Students are taught to apply design thinking as an integral part of the innovation process to bring forth ideas that can improve the lives of people. They will learn by taking a project through all its stages – from conceptualisation, planning, designing to building the prototypes and models and presenting their marketing plans. The ChangeMakers Programme will also involve industry partners to provide students with insights of real world applications in various areas, and where possible, mentor students working on selected projects.

In addition, as part of their Talent Development Programme, SST also provides opportunities to uncover, nurture, and celebrate students' strengths, talents, and sustained interests, starting from what they are good at. SST's strong partnership with Nanyang Technological University (NTU), Singapore University of Technology and Design (SUTD), and Ngee Ann Polytechnic (NP) as well as leading industry players such as 3 M, Apple Inc. and DSO National Laboratories, has exposed students to varied and enriching learning opportunities in STEM.

3.3 Key Challenges and Directions for Future Research

The snapshots of the STEM initiatives in Singapore have highlighted the different pathways we have taken to step up our STEM education. These initiatives have built on the foundations of a strong educational system, while providing a supportive environment for *a thousand flowers to bloom*. However, it is now timely for us to acknowledge and address the four main issues facing STEM education in Singapore so that we can move forward in our STEM agenda.

First, as highlighted by English (2016), there has been uneven representation of the different disciplines in STEM. In particular, mathematics and engineering are under-represented in many studies on STEM education. Without a clear universally-accepted definition of STEM and STEM education, it will be challenging to design, implement, and assess STEM education programmes. Although Vasquez's (2014/15) ideas of multi-disciplinary, inter-disciplinary, and trans-disciplinary forms of learning may provide a way to depict the different degree of connections between the separate disciplines, it remains vague how teachers, school leaders, and policy makers can ensure that students learn the core disciplinary ideas of science, technology, engineering, and mathematics, while they focus on the integrative applications of these ideas. Getting some form of clarity *and agreement* with regard to the definitions of STEM and STEM education will be critical for STEM education to grow and flourish. The S-T-E-M Quartet proposed by Tan, Teo, Choy, and Ong (2019) may also provide a common base for educators and researchers to start thinking about STEM in terms of the deep connections *within* and *between* the four disciplines. Whether, and if so how, the S-T-E-M Quartet can facilitate the design, implementation, and review of STEM lessons in the classrooms will be an important area of research to pursue.

Second, if the focus on solving complex STEM problems were to be the centre of our STEM endeavours, what kind of student outcomes should we aim for? The issue of student outcomes is also related to the integrative nature of STEM. Unlike a singular discipline, the knowledge, skills, and dispositions espoused in the curriculum documents of a STEM curriculum cannot be a simple amalgamation of the knowledge, skills, and dispositions of the four disciplines. Instead, it has to be built on what is common and yet central to each of the disciplines and articulate what is different but yet central to the enterprise of STEM as a whole. Resolving this tension between maintaining the balance between discipline-specific outcomes and STEM-centric outcomes will be critical for educators as they begin to articulate the desired student outcomes of a STEM curriculum.

Third, we need to address another critical issue should we want to develop STEM competencies through our education systems—What is a STEM classroom and how does it look like? What would students be doing in such a classroom? What kind of resources, tools, and environmental structures are needed in order to enact a productive STEM curriculum? These questions have no easy answers and answering them requires us to think more deeply about the previous two issues—definitions of STEM and desired student outcomes. Part of the STEM agenda is to change the way we teach each of these disciplines: from one that focuses solely on the disciplinarity of the subjects to one that builds on the disciplinarity of each subject and harnesses the affordances of each subject to solve real-world problems. Perhaps, our future research needs to focus on developing evidence-based classroom exemplars of STEM curriculum implementation so that we can identify some of the essential features of a good STEM programme.

Last, if we envision STEM to be an integrative and connected enterprise, focusing on the dispositions central to each of the four disciplines, what competencies do teachers need? More importantly, how do they develop such skills? While the idea of developing a *Da-Vinci* type of teacher, who is a universalist—someone who is strong in each of the disciplines—may seem attractive, it may not be practically possible. This is so considering that many teachers are *specialists* in the secondary schools and *generalists* in the primary schools. Moreover, today's problems are often complex and requires experts with different skills to collaborate and work on the problems together. Consequently, requiring teachers to develop expertise in each of the disciplines may not be the way forward. Instead, we may have to re-envision how teachers may collaborate in a STEM classroom to design, implement, and review a STEM curriculum. Re-envisioning STEM teaching will not only provide a better understanding of the competencies needed by a STEM teacher, but also the productive *mindsets* of a STEM teacher. Doing this will definitely go a long way in providing a clearer direction for our professional development efforts.

Even though these issues are challenging and may even threaten the future of STEM education, we could also see these issues as opportunities to build on our existing strengths and seek new partnerships with STEM stakeholders to design new and relevant learning experiences for our STEM students.

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