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Chapter 1
An Overview of STEM Education in Asia

May May Hung Cheng

Abstract This introduction chapter provides an overview of STEM education policies and curriculum initiatives in the Asian context. The three parts of this book are briefly introduced. There is then a summary and synthesis of relevant findings for each of the 14 chapters as well as a discussion linking the content of this book with the current development of STEM education research. Finally, implications, challenges and future directions for STEM education development and related research are proposed.

Keywords Conceptualising STEM education · Implementing STEM education · Teacher preparation · Teacher professional development

STEM Education in Asia: Contributing to an International Discourse

Concurrent with the global drive for STEM education, research in STEM education has shown exponential growth in the past decade (Brown, 2012; Lee et al., 2019; Mizell & Brown, 2016). Much attention has been given to integrating STEM education, shifting from previous STEM subject implementation that traditionally focused on science, technology, engineering, and mathematics as isolated disciplines (Brown, 2012; Kelley & Knowles, 2016; Lee et al., 2019; Wang et al., 2011) or which used examples of technology to contextualize science education (science-technology-society, STS) (see Jones & Buntting, 2015). However, implementing integrated STEM is not straightforward. Some of the challenges arising from achieving integration in STEM education, documented in recent research, include areas of concern such as curriculum enrichment of existing subjects like science or restructuring STEM-based discipline curricula (Nadelson &

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Seifert, 2017) and teacher preparation and professional development (Al Salami et al., 2017; Asghar et al., 2012; Lee et al., 2019). Researchers have also called for a better understanding of STEM curricula as well as classroom practices and operations due to a lack of empirical evidence discerning elements crucial for a successful implementation of STEM education (Honey et al., 2014; Kang, 2019; Thibaut et al., 2018).

Despite global attention to STEM policy and an increase in STEM education research, Asian-based STEM education studies are still in an emerging state in the international literature. According to Lee et al.'s (2019) editorial article, Asian-based STEM education studies comprised only 8.5% of the total examined international STEM education publications from 2013 to 2017 ($N = 665$), compared to around 65% from the United States. There are also increasing calls for schools to design integrated STEM units that improve, or at least preserve, students' examination results while concurrently fostering the knowledge, skills, and attitudes needed for the 21st century. Little is known about the best practices for implementing or integrating STEM in ways that will do this (English, 2016; Herschbach, 2011; Kelley & Knowles, 2016), especially in the Asian context.

After more than a decade of STEM education promotion in many Asian countries, an analysis of the current status and practices in the region is not only timely, but it provides a reference to inform future STEM education and research initiatives in the Asian region. Thus, the purpose of this edited book is to enrich the literature related to STEM education at primary and secondary levels in Asia, with particular attention given to the analysis of the educational context in a number of Asian countries, including STEM-related policies, pedagogical practices, and the design and evaluation of STEM programmes, including impacts on student learning outcomes and the ways in which STEM education is catering for students' interests and needs. Together, the contributions from different Asian regions invite researchers and educators to learn from effective STEM practices, and point out areas for further development.

The Asian Region is well-known for its wide range of geographical, political, economic, and religious diversity between and within the countries in the region. Given these variations, and the insights arising from the differing contexts, international readers will be able to gain insights from the ways in which STEM learning and teaching initiatives have been tested, modified, and developed in a range of highly complex and diversified contexts. Further, the specific resources and strategies outlined in this book can be a useful reference for all curriculum developers and STEM educators when they design school-based curricula and STEM teacher education or development programmes. Graduate students and researchers will find in this book contextual information related to STEM education in Asia, directions for further investigation, and insights for conducting studies in this region.

STEM Education Policies and Curriculum Initiatives in the Asian Context

A brief introduction of STEM policies and curriculum practices in the Asian context provides a useful backdrop for understanding the content of this book. In a comprehensive review of international STEM education policy, Marginson et al. (2013) categorized different STEM policy narratives into four groups, including Post-Confucian East and Southeast Asia, English-speaking countries, Europe, and the emerging economies and education systems (e.g. South Africa, Brazil, and Argentina). Their review identified a common economic discourse on the contribution of STEM education to individual nations' economic innovation in response to the challenges of the 21st century, and highlighted diverse narratives embedded in different discursive terrains. In the Asian region, more emphasis has been placed on improving teacher quality to meet higher standards, having high standard provision of STEM education for all (specifically in Science and Mathematics), and driving comprehensive reforms towards pedagogical approaches that emphasize student-centred learning, inquiry-based learning, problem solving, and creativity. Comparatively, a widespread 'at risk' narrative underpinned by student under-performance and long tails of low-achievers in international achievement tests, declining student participation in STEM subjects, and concerns related to the general quality of the teachers are more pervasive among the majority of English-speaking countries. These findings suggest a difference in focus and concerns related to STEM education in different parts of the world.

To further support readers' understanding of the development of STEM education in Asia, a brief overview is provided for Mainland China, Japan, Singapore, Thailand, Taiwan, Hong Kong, Malaysia, Korea, and Indonesia.

Within Asia, the Korean Ministry of Education, in 2011, reconstructed STEM education to incorporate 'Arts,' making STEAM an interdisciplinary construction for 'creative convergence education' (Marginson et al., 2013; Park et al., 2016). The Korean STEAM initiatives were spurred by continuous government projects for human development (e.g. Educating Talented and Gifted Youth in Science; see Jon & Chung, 2013), and recent international comparison studies indicating students' high performance yet low-level of interest and enjoyment in science and mathematics (Organisation for Economic Co-operation & Development, 2010). At the school level, individual components of STEAM are required to be taught to primary and secondary school students (Kang, 2019). Furthermore, key objectives of 'creative convergence education' are materialized in the course of 'creative experiences' (taking up to 9–13% of total class hours) in the National Guidelines of the 2015 Revised National Curriculum (Cho & Huh, 2017; Kang, 2019). Nationally, the Korea Institute/Foundation for the Advancement of Science and Creativity (KOFAC), as the most representative government agency for STEAM, has played a major role in organizing STEAM programmes and initiatives. KOFAC defines STEAM as education based on scientific technology, and has driven STEAM initiatives through supporting the science culture and maker cultures; supporting professional development of teachers and resource development and distribution in creative convergence education; and supporting gifted youth (Hong, 2017; KOFAC, n.d.).

In Japan, policies and programmes that affect various aspects of STEM education are addressed under broader discussions of science, technology, and human resources development, the synthesis of broad-based education and the 'STEM for STEM people' elite track, the 'PISA shock', and the re-evaluation of a 'low pressure and relaxing' curriculum characterizing the 2000s (Ishikawa et al., 2013; Marginson et al., 2013; Takayama, 2010). Within the context of the national curriculum, the 2008 Revision of Courses of Study, or the national curriculum guidelines implemented by the Japanese Ministry of Education, Sports, Science, and Technology stipulated increased contact hours as well as content in Science and Mathematics subjects for primary and lower secondary schools. In addition to the nationwide curriculum provision, other STEM promotion strategies included the launch of specialist or 'elite' science programmes (for secondary and tertiary level), addressing gender disparity in STEM participation and occupation, and STEM-discipline student internationalization initiatives (Ishikawa et al., 2013; Marginson et al., 2013).

In Singapore, STEM education has long been part of the framing of national policy on education and industry. Its perceived relevance to the industry is reflected in the current movement of the 'innovation-driven' economy since 2000 (Idris et al., 2013). Within the national curriculum context, STEM education in formal schooling in Singapore is embedded in Mathematics Education and Science Education in both primary and secondary schools. In addition to discipline-based integration, a state-wide STEM education programme, mostly in the form of extracurricular activities, is provided by the Agency for Science under the supervision of the Ministry of Education to promote STEM education in Singapore (Idris et al., 2013).

In Mainland China, school-, city-, and provincial-based STEM programmes for primary and secondary schools represent a bottom-up approach to STEM education in Mainland China involving different stakeholders (e.g. universities, research centres, industry, etc.). Interest in STEM education and research, initiated by the introduction and analysis of STEM education and policy in the country, started to take root in 2007. The 'China STEAM Development Report', co-authored by the Ministry of Education People's Republic of China (MOE P. R. of China) and other educational and research institutes, pointed out several characteristics of STEAM education in Mainland China. First, around 72% of STEAM-related courses are embedded in extracurricular activities or elective courses. Second, within the formal curriculum context, the current implementation of STEM education in Mainland China is primarily school-based and embedded in non-core subjects (e.g. information technology), with engineering as a core aspect, and strong application features (e.g. coding, robotics, and media production) (MOE P. R. of China et al., 2017).

In Hong Kong, a Special Administrative Region of China, the government officially addressed the importance of STEM education and started promoting

STEM education in primary and secondary schools in 2015 (Education Bureau of Hong Kong [EDBHK], 2016). Within the Hong Kong curriculum context, the elements of STEM education are embedded in the three key learning areas (KLAs) of Science, Technology, and Mathematics Education, with key strategies focusing on the curriculum renewal of the KLAs enriching learning activities, and enhancing teacher education for strengthening STEM education (EDBHK, 2016).

In Taiwan, the K-12 curriculum guidelines issued by the Ministry of Education in 2018 (Ministry of Education of Taiwan, 2018) integrate the STEM subjects into the science and technology curriculum. There are efforts to further promote the core literacies of systematic thinking and problem solving for all citizens in order to promote competition and enhance expertise in the technology industry.

In Malaysia, an 'at-risk' mindset was prevalent in relation to low intakes of science and technology courses and programmes despite the implementation of the national enrolment policy since the 1970s (Shahali et al., 2017). Additionally, the crisis of an insufficient STEM workforce for the future and a downward trend of test scores in TIMSS and PISA have dominated the official STEM narratives in the country (Marginson et al., 2013; Shahali et al., 2017). This perception of national crisis drove the Malaysian Ministry of Education to stress the quality of STEM education for enhancing students' STEM knowledge and interest in science subjects under the broad *Malaysia Education Blueprint* promulgated in 2013 (Ministry of Education Malaysia, 2013). In the context of the Malaysian primary and (lower) secondary education curricula, STEM education initiatives are embedded primarily in the 'Core Science Subjects' through the planning of an integrated STEM approach in teaching and learning (Shahali et al., 2017). In the upper secondary curricular context, the nomenclature 'STEM stream' has replaced the term 'Science & Technology Stream' (previously renamed from 'Science Stream') since 2020 in the Malaysian school system.

In Thailand, STEM education was on the agenda of the Ministry of Education in 2015, with the inclusion of STEM education in the Thai National Education plan in 2017 (Office of the Education Council Thailand, 2017). Efforts to promote STEM education start from the Early Childhood Education sector, and include science, mathematics, and technology in the curriculum. The primary and secondary curricula for mathematics, science, and geography were revised, while design and technology and information and communication technology were moved into the science curriculum (Ministry of Education Thailand, 2017). As a result, the technology strand in the science learning area includes design and technology as well as computational thinking. STEM education in Thailand is driven and promoted by a number of organizations, including large corporations and non-government organizations, in addition to schools and universities.

In Indonesia, according to the curriculum goals of science education for K-12, there is an emphasis on integrating science concepts with technology, environment, and society (Indonesia Ministry of Education and Culture, 2020). Research efforts to promote teacher education for STEM education have found that Indonesian pre-service teachers have low understanding of integrated STEM approaches (Putra & Kumano, 2018).

Having provided an overview of macro-level STEM education policies and curriculum initiatives in the Asian contexts presented in this book, the structure of the book is now considered, including an introduction to the individual chapters.

The Three Sections of This Book

This book has a further 14 chapters, written by contributors from nine countries or regions in Asia. It is divided into three sections focusing on the conceptualization of, implementation of, and teacher preparation for STEM education. The contributors are experts in STEM education or are leading major research and development projects in STEM in their own regions. The first section is focused at the macro-level on the conceptualization and formulation of STEM education policies in different regions, contributing to our understanding of the current status of STEM education in Asia. The second section examines some features of STEM learning and teaching at the classroom level and includes studies on student learning in STEM programmes. Pedagogical innovations implemented in different parts of Asia are also reported and discussed. The third section moves to professional teacher development. It discusses practices of teacher professional development in the region and reports on current provisions as well as challenges.

This introduction chapter provides below a synthesis of the relevant findings reported in the remaining chapters, as well as linking the content of this book with the current development of STEM education research. Finally, some directions for future research on STEM learning and teaching in Asia are proposed.

Conceptualizing STEM Education in Asia

The three chapters in this section cover discussions of STEM policies, directions, and programmes across different regions in Asia. The section begins with Chap. 2, a review of STEM strategies and programmes in secondary education in Asia. The review draws on 32 papers written in English published between 2011 and 2020 and written in the Asian context. Guided by descriptive frameworks drawn from analysis of good practices of integrated STEM, STEM courses and programmes were examined in terms of the nature and scope of STEM programmes, instructional practices adopted in the STEM programmes, and the evidence of the impact of the STEM programmes on student learning in the knowledge, skills, and attitude domains. This review characterizes different STEM enactments in Asian secondary education, contributing to identifying and discussing effective STEM programmes and strategies.

In Chap. 3, STEAM education is reported to be adopted widely in theoretical research and educational practices in Mainland China by colleagues, Meng et al. STEAM education in Mainland China is informed by the Core Competencies and

Values (CCV) for Chinese Students (MOE P. R. of China, 2016), in which there are four specific aspects: scientific concepts and applications, scientific thinking and innovation, scientific exploration and communication, and scientific attitudes and responsibilities. The chapter explains the alignment of policies at the provincial and regional level as well as the formulation of STEM learning and teaching strategies, characteristics of STEM learners in Mainland China, research collaborations in STEAM learning, teaching approaches, and the practice of teacher professional development related to STEAM education.

In Chap. 4, Yoshisuke Kumano positions the discussion of STEM education in Japan in the context of the third largest economy in the world. He draws on the implications of the developments of STEM/STEAM learning in the United States and policy directions by the Japanese government, which chart the role of STEM education for the future society, that is, 'Society 5.0' as defined by the Cabinet of Japan (Cabinet Office of Japan, 2021). Kumano shares how policy is translated into action with the Shizuoka STEM Academy and concludes the chapter by calling for joint effort from schools, institutions, companies, and policymakers in addressing the needs for the future society.

Implementing STEM Education in Asia

The eight chapters in this section cover contributions from six different regions in Asia: Singapore, Thailand, Taiwan, Hong Kong, Malaysia, and Korea. Together, the chapters also consider STEM education across the early childhood, primary, and secondary education levels and urban and rural settings. A range of initiatives is reported, including considering formal and informal learning opportunities, adopting an engineering design process, implementing online experiments, engaging in scientist-teacher-student partnerships, promoting mentor–mentee learning within university school partnerships, and using the scientific research process to promote STEM learning.

Yann Shiou Ong and Yew Jin Lee analyse the implementation of STEM education in the Applied Learning Programmes (ALP) in Singapore by reviewing the websites of 15 secondary schools in Chap. 5. They use a theoretical model of relevance of STEM education, defining the relevance of STEM education for students in relation to fulfilling intrinsic or extrinsic needs in the present or in the future, and individual, societal, and vocational needs. The chapter concludes with three implications, including the need for consideration of student choices, awareness and discussion of the undesirable impacts of STEM solutions, and an emphasis on the epistemic aspects of STEM.

In Chap. 6, Promkatkeaw et al. discuss education policies in Thailand and the rationale for emphasizing STEM at the Early Childhood Education (ECE) level. There are clear directions for integrating science, mathematics, and technology in ECE in the Thai curriculum with an aim of promoting inquiry, communication, and thinking skills at an early age as described in the curriculum standards. The implementation is supported by professional development for ECE teachers, provision of STEM activities or lesson plans adopting an engineering design process and learning resources, as well as research efforts focusing on the impact of STEM learning on the cognitive development of young children. The chapter concludes with a call for the development of learning materials and lesson activities, and embedding the United Nations' sustainable development goals into STEM learning.

With an aim of promoting STEM learning to all students including girls in Taiwan, Meng-Fei Cheng and Yu-Heng Lo (Chap. 7) designed a 3-hour course to enhance students' creativity and engage them in an engineering design process. Cheng and Lo analysed the need for girl-friendly STEM education, and adopted various strategies in the course including providing a low-stress environment, creating a cooperative rather than competitive learning environment, and open-ended assessment. Findings suggest that the course reduced the gender gap in terms of enhancing the engineering design ability and attitudes towards technology among all students.

The online experiments (OEs) or remotely-controlled experiments introduced in Chap. 8 by Yau Yuen Yeung and his colleagues won a special prize in an international innovation and invention competition in 2018. The OEs which involve the use of technology and knowledge in science experiments were introduced to four secondary classes of students in Hong Kong and Mainland China. Findings suggest that students of both genders generally gained good science or STEM learning experiences. The chapter concludes with recommendations for designing OEs and the application of OEs, for example, during times of crisis like the COVID-19 pandemic, and where schools are not able to offer laboratory practice or for experiments that require extra precautions or extended time periods.

In Chap. 9, Rohaida Mohd Saat and Hidayah Mohd Fadzil explain how STEM is reflected in Malaysian education policies and school curriculum choices. There are defined STEM subject areas such as Science and Computer Science, STEM Core Subject Packages, STEM elective subjects, and Applied Science and Technology subjects for the STEM stream. Teaching and learning approaches such as inquiry-based and project-based learning are identified as being relevant for STEM. The three waves of initiatives to promote STEM are elaborated, and a detailed analysis of the Scientist-Teacher-Student Partnership (STSP) approach is analysed, with discussion of the roles of the different parties and the factors contributing to the success of the approach.

The STEM initiative in Chap. 10 is contextualized in the rural areas of East Malaysia, Sabah. Nyet Moi Siew reports on the implementation of a mentor–mentee programme involving secondary students, as well as in-service and pre-service teachers. The STEM activities were implemented using an engineering design process, aiming to develop the students' 21st century skills. Quantitative and qualitative data were collected over a five-year period to evaluate the outcomes of the programme and to identify challenges. Findings suggest benefits for developing students' thinking and creativity, problem solving skills, and skills involved in sketching, designing, and constructing models. Two challenges for the mentees or students were time constraints for completing their plans and limited understanding of scientific concepts.

In Chap. 11, Jiyeong Mun and Sung-won Kim elaborate on the development of STEM education in Korea and support from the Ministry of Education as well as the KOFAC. Details are provided about a STEM R&E (research and education) programme funded by the KOFAC, in which students were involved in a scientific research process including drafting proposals, applying for grants, consulting experts, and making presentations. Involving students as future scientists facilitates students' development of research skills, problem-solving abilities, and collaboration and peer cooperation skills. Students reflected that they learned both from their achievement and failures in the research process.

In Chap. 12, Hye-eun Chu et al. report how STEAM education is realized in Korean classrooms, using three school-based projects as illustrations. Teachers in both Korea and Australia were implementing the projects and testing out various teaching approaches to realize STEAM education. The first project illustrates a four-phased teaching design for adopting the STEAM approach. The second project involves an arts activity for designing a quasi-3D hologram using a mobile phone or iPad and a pyramid made of clear plastic. Interview findings about students' perceptions of learning science are summarized in relation to this project. The third project looks into the impact of STEAM on scientific creativity by involving students in designing a sustainable school building. The experience of these projects provides reference for teachers who are teaching in traditional classroom settings while attempting to implement STEAM education.

Preparing Teachers and Teacher Professional Development for STEM Education in Asia

The three chapters in this section together address teacher preparation for STEM education at both the pre-service and in-service levels. The contributions from Indonesia (Chap. 13) and Thailand (Chap. 14) are based on analysis of existing provision and information from websites or university programme materials. The chapter from Hong Kong (Chap. 15) reports on data collected from in-service teachers, recommending directions for professional development to facilitate STEM implementation at the school level.

Thus, in Chap. 13, Sulaeman et al. provide background to K-12 science education in Indonesia, pathways to become a science teacher, and the curriculum of science teacher preparation programmes. Drawing on information from the websites of three universities, Sulaeman et al. identify several strategies adopted by the universities in re-designing their programmes to address STEM teacher preparation needs, including designing a new compulsory course in STEM education, integrating STEM into other pedagogical courses, and providing elective courses and extra-curricular activities. Further opportunities to develop STEM pedagogical content knowledge through pre-service science teacher education programmes are proposed.

Chapter 14 provides a background on the Thailand 5-year STEM Master Plan from 2015 to 2019 for increasing the number of trained personnel to serve the STEM education policies. In this context, STEM education is promoted in the core curriculum, requiring urgent teacher development. Specifically, Fakcharoenphol et al. argue for strengthening support for both pre-service and in-service teachers in implementing STEM education, including covering different subject areas, not limited to science and mathematics. The chapter reports on the findings of a meta-analysis of research related to STEM teacher education in Thailand. Implications indicate directions for further support and development, including the setting up of communities of practice, developing teaching materials or resources, reforming student assessment, and reminding teachers to focus more on capturing students' interest and engaging them in evaluating their design or invention.

In Chap. 15, the findings are reported for a STEM education project that was conducted in collaboration with Hong Kong primary schools to enhance primary school teachers' professional ability to develop STEM activities. The project adopted a practitioner research approach in collaboration with the university research team, and teachers participating in the project were interviewed. The findings revealed participating primary school teachers' perceived challenges in implementing STEM education, the support they received, and their future needs in STEM teacher professional development. Challenges reported during the preparation and teaching phases were related to STEM instruction and lesson planning, limited resources, and other concerns embedded in broader contextual considerations. Participating teachers also indicated a preference for future STEM teacher professional development activities that address lesson content, pedagogical approaches and lesson planning; provide opportunities for authentic learning and hands-on experiences; and consider the linkages between STEM lessons and even the linkage or development of a framework describing STEM learning between the primary and secondary levels.

Implications, Challenges, and Future Directions

These chapters provide evidence for Asian-based STEM education studies within the worldwide landscape calling for and supporting widening participation in STEM education. Additionally, school-level STEM education has been much less studied compared to that in the higher education sector (Lee et al., 2019). The chapters in this book therefore add to the literature related to current practices in STEM education in schools around Asia.

Importantly, the chapters reflect some of the tremendous efforts underpinning and driving STEM education in Asia. For example, STEM education is seen as a meaningful endeavour informed by a vision to prepare for a future society in Japan (Chap. 4), and it is supported by organizations and foundations investing in the next generation, such as KOFAC in Korea (Chaps. 11 and 12), and non-government organizations in Thailand (Chap. 6). There are efforts in curriculum revision and development in Indonesia, Taiwan, and Thailand. Further, the benefits of university-school partnership projects are reported in the contexts of Hong Kong (Chaps. 8 and 15), Thailand (Chaps. 6 and 14), and Singapore (Chap. 5), with benefits of involving the research community in mentor–mentee programmes described in the context of Malaysia (Chap. 10).

Together, the chapters in this book reveal that different regions in Asia have been implementing STEM education in new ways at different levels of education. For example, initiatives are described for early childhood education in Thailand, the primary level in Hong Kong, and secondary schools in Japan, Korea, Thailand, Indonesia, and Singapore. In defining STEM education practices, the chapters in this book have consistently employed the term STEM in their analysis and as the focus of their study. Among the chapters included in this book, efforts to integrate STEM with other subject areas and STEAM initiatives are described in the context of Korea and Mainland China. Further efforts are needed to examine the implications of STEM education for early childhood and primary schools. In addition, the impacts of STEAM education as compared with STEM education on student learning warrant further attention.

Researchers contributing to this book were keen to identify changes in students' learning and attitudes towards STEM. Two of the Chaps. (7 and 8) specifically identify changes in students' attitudes towards STEM learning at school, or how STEM learning experiences may impact on their choices for future study or careers. The focus of Cheng's study in Chap. 7 on the impact of STEM initiatives on female students to enhance the future pool of human capital for the technology or engineering sector reflects international interest in gendered responses to STEM education initiatives. For example, Kang (2019) investigated the usefulness and usability of online media in technology-supported STEM learning, finding that having STEM experiences during elementary school had a long-term impact on university students' affective learning. In addition, STEM initiatives for female students may also be interpreted as a move towards nurturing all students to achieve basic STEM literacy and ensure equal learning opportunities. Continued research into the impacts and ways of enhancing the impacts of STEM education on students' learning is important.

Some of the approaches to delivering STEM education at the school level include partnerships with experts and organizations beyond schools. For example, there are efforts to involve scientists and engineers in industry to mentor students through industry-school partnerships in Japan and Korea (Chaps. 4 and 11). Specifically, students in these examples were offered opportunities to carry out authentic research projects guided by teachers and working with scientists or engineers. One of the many benefits of this approach is that students may identify role models for their future careers, thus influencing their perceptions of or attitudes towards choosing technology or engineering related jobs in their future careers.

While many of the chapters identify positive impacts of integrating STEM into an existing subject or curriculum, this is nonetheless challenging, as discussed in

Chaps. 12, , 14, and 15. The fact that engineering and technology components are often not explicit or visible in the curriculum core components suggests that the STEM acronym more frequently references science in the actual implementation of STEM curricula and classroom practices in the Asian context. According to the review by Marginson et al. (2013), many Asian regions refer to the role of STEM education as one that fosters 'broad-based scientific literacy' (p. 70). In order to implement STEM education as an integrated learning experience for all students, teachers need to understand its interdisciplinary nature, realize the differences in its implementation as compared to implementing traditional (siloed) subject learning, and have the experience of STEM learning themselves (as suggested in Chap. 15).

It remains challenging for the many aims of STEM education to be fully achieved. As demonstrated across this book, the challenges include curriculum design, teacher preparation and development, implementation at the school and classroom level, resource support, and assessing the impacts of the initiatives. Further studies are needed to identify solutions to address the challenges. For example, it is worth investigating the impacts of providing teachers with STEM learning experiences (as suggested in Chap. 15), constructing a teacher education curriculum to prepare teachers who have not experienced STEM education in their previous education (Chaps. 13 and 14), supporting teachers to develop a different mindset as compared with views in which traditional teaching rewards correct and uniform solutions (Chaps. 12 and 15), facilitating collaborations between teachers and industry or the research community (as discussed in many of the chapters), and enhancing teachers' capacity to use technology in their teaching (Chap. 8).

Researchers may facilitate teachers' professional development by engaging teachers in collaborations with universities, for example, in practitioner research that involves developing STEM lessons that address students' needs, such as the needs of female students; building coherence between STEM topics; and developing teachers' ability and confidence in relation to teaching unfamiliar topics, for example, science teachers teaching coding or engineering.

At the macro-level, the effective embedding of integrated STEM education will require administrators and education officials to support the implementation of STEM education at both the school and the system level, including providing time and opportunities for professional development, funding the development and sharing of teaching resources, creating curriculum time for STEM lessons or projects, and valuing new approaches to assessment. While the pursuit of STEM may mark a new era for education and offer new opportunities for students, the education community in its broadest sense needs to be prepared to embrace the changes as well as the challenges. It is our collective hope that this book provides some inspiring insights into ways in which this might be done.

References

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education, 27*(1), 63–88. https://doi.org/10.1007/s10798-015-9341-0.

Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM education in secondary science contexts. *Interdisciplinary Journal of Problem-Based Learning*, *6*(2), Article 4. https://doi.org/10.7771/1541-5015.1349.

Brown, J. (2012). The current status of STEM education research. *Journal of STEM Education: Innovations and Research*, *13*(5), 7–11. https://www.jstem.org/jstem/index.php/JSTEM/article/view/1652.

Cabinet Office of Japan. (2021). *Kagakugijyutsu Innovation Kihon Keikaku* [Science, technology, and innovation basic plan]. Government of Japan. https://www8.cao.go.jp/cstp/kihonkeikaku/6gaiyo.pdf.

Cho, J., & Huh, J. (2017, December 20). *New education policies and practices in South Korea*. UNESCO. https://bangkok.unesco.org/content/new-education-policies-and-practices-south-korea.

Education Bureau of Hong Kong. (2016). *Report on promotion of STEM education: Unleashing potential in innovation*. Education Bureau. https://www.edb.gov.hk/attachment/en/curriculum-development/renewal/STEM%20Education%20Report_Eng.pdf.

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(3), 1–8. https://doi.org/10.1186/s40594-016-0036-1.

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. *Journal of STEM Teacher Education*, *48*(1), 96–122. https://doi.org/10.30707/JSTE48.1Herschbach.

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and anagenda for research*: National Academies Press. https://doi.org/10.17226/18612.

Hong, O. (2017). STEAM education in Korea: Current policies and future directions. *Asian Research Policy, 8*(2), 92–102.

Idris, N., Daud, M. F., Meng, C. C., Eu, L. K., & Ariffin, A. D. (2013). *Country comparisons: Country report Singapore STEM*. Australian Council of Learned Academies (ACOLA). https://acola.org/wp-content/uploads/2018/12/Consultant-Report-Singapore.pdf.

Indonesia Ministry of Education and Culture. (2020). *Fokus Pembelajaran SD/MI, SMP/MTs, SMA/MA*. [Learning focus for elementary school and middle school]. Badan Standar Nasional Pendidikan. https://bsnp-indonesia.org/fokus-pembelajaran/.

Ishikawa, M., Fujii, S., & Moehle, A. (2013). *Country comparisons: Japan*. Australian Council of Learned Academies (ACOLA). https://acola.org/wp-content/uploads/2018/12/Consultant-Report-Japan.pdf.

Jon, J.-E., & Chung, H.-I. (2013). *Country comparisons: Country report—Republic of Korea*. Australian Council of Learned Academies (ACOLA). https://acola.org/wp-content/uploads/2018/12/Consultant-Report-Korea.pdf.

Jones, A., & Buntting, C. (2015). Technology education and science education. In R. Gunstone (Ed.), *Springer Encyclopedia in Science Education* (pp. 1049–1053). SpringerReference.

Kang, N. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education*, *5*(6). https://doi.org/10.1186/s41029-019-0034-y.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), 1–11.

Korea Institute/Foundation for the Advancement of Science & Creativity. (n.d.). *Spreading science culture and maker culture*. https://www.kofac.re.kr/wp-content/uploads/2018/KOFAC_BROCHURE.pdf.

Lee, M. H., Chai, C. S., & Hong, H. Y. (2019). STEM education in Asia Pacific: Challenges and development. *Asia-Pacific Education Researcher, 28*(1), 1–4. https://doi.org/10.1007/s40299-018-0424-z.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons. International comparisons of science, technology, engineering and mathematics (STEM) education: Final report.* Australian Council of Learned Academies (ACOLA). https://acola.org/wp-content/uploads/2018/12/saf02-stem-country-comparisons.pdf.

Ministry of Education Malaysia. (2013). *Malaysia education blueprint 2013–2025*. (*Preschool to post-secondary education*). Kementerian Pendidikan Malaysia. https://www.moe.gov.my/menumedia/media-cetak/penerbitan/dasar/1207-malaysia-education-blueprint-2013-2025/file.

Ministry of Education People's Republic of China. (2016). *Jiàoyù bù guānyú yìnfā "jiàoyù xìnxī huà "shísānwǔ" guīhuà" de tōngzhī* [The 13th five-year plan for educational informatization]. http://www.moe.gov.cn/srcsite/A16/s3342/201606/t20160622_269367.html.

Ministry of Education People's Republic of China, Beijing Normal University, & Beijing World Education and InformationTechnology Research Institute. (2017). *Zhōngguó STEAM jiàoyù fāzhǎn bàogào* [China STEAM development report]. Beijing Normal University.

Ministry of Education of Taiwan. (2018). *Shí'èr nián guómín jīběn jiàoyù kèchéng gāngyào—zìrán kē lǐngyù* [Curriculum Guidelines of 12-Year Basic Education—Science Education]. The Ministry of Education of Taiwan.

Ministry of Education Thailand. (2017). *Tạw chī̂ wạd lœa sāra kār reīyn rū̂ kæn klāng klùm sāra kār reīyn rū̂ withyāṣāstr̒ (chbạb prạbprung ph.Ṣ. 2560) Tām hlạksūtr kæn klāng kār ṣụks'ā khận phụ̂nṭhān phuthṭhṣạkrāch 2551* [Indicators and core learning areas science (Revised B.E. 2560) based on the basic education core curriculum B.E. 2551]. Office of the Basic Education Commission, MOE. https://drive.google.com/file/d/1_ALwE9xuCL3Fjet3XI4gYjBj8p_1zLaA/view.

Mizell, S., & Brown, S. (2016). The current status of STEM education research 2013–2015. *Journal of STEM Education*, *17*(4), 52–56. https://www.jstem.org/jstem/index.php/JSTEM/article/view/2169.

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research, 110*(3), 221–223. https://doi.org/10.1080/00220671.2017.1289775.

Office of the Education Council Thailand. (2017). *Phænkār ṣụks'ā hæ̀ng chāti ph.Ṣ. 2560–2579* [Thai national education plan A.D. 2017–2036]. https://planipolis.iiep.unesco.org/sites/default/files/ressources/thailand_educationplan.pdf.

Organisation for Economic Co-operation and Development. (2010). *PISA 2009 results: What students know and can do–student performance in reading, mathematics, and science* (Vol. I). OECD Publishing. https://doi.org/10.1787/9789264091450-en.

Park, H., Byun, S.-Y., Sim, J., Han, H.-S., & Baek, Y. S. (2016). Teachers' perceptions and practices of STEAM education in South Korea. *Eurasia Journal of Mathematics, Science and Technology Education, 12*(7), 1739–1753. https://doi.org/10.12973/eurasia.2016.1531a.

Putra, P. D. A., & Kumano, Y. (2018). Energy learning progression and STEM conceptualization among pre-service science teachers in Japan and Indonesia. *New Educational Review*, *53*(3), 153–162. https://doi.org/10.15804/tner.2018.53.3.13.

Shahali, E. H. M., Ismail, I., & Halim, L. (2017). STEM education in Malaysia: Policy, trajectories and initiatives. *Asian Research Policy, 8*(2), 122–133.

Takayama, K. (2010). Politics of externalization in reflexive times: Reinventing Japanese education reform discourses through "Finnish PISA success." *Comparative Education Review, 54*(1), 51–75. https://doi.org/10.1086/644838.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knippraath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2. https://doi.org/10.20897/ejsteme/85525.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(2), Article 2. https://doi.org/10.5703/1288284314636.

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Part I
Conceptualising STEM Education in Asia

Chapter 2
Identifying Effective STEM Programmes and Strategies in Asia

May May Hung Cheng and Fang-Yin Yeh

Abstract This chapter reports a systematic review of existing literature related to the study of STEM in Asian secondary education. Thirty-two studies published in English from 2011 to 2020 were selected and reviewed. Guided by descriptive frameworks drawn from analysis of good practices of integrated STEM, STEM courses and programmes in Asia were examined in terms of firstly, the nature and scope of STEM programmes, secondly, instructional practices adopted in the STEM programmes, and thirdly, the evidence of the STEM programme impact on student learning in the knowledge, skills, and attitude domains. The findings showed that in addition to the frequent emphasis on science learning, an emerging trend of integrating engineering design at the secondary school level was observed among the existing Asian-based STEM programmes and courses. Additionally, project-based learning and engineering design-based learning were two main instructional designs used among the selected studies that demonstrated the flexibility in meeting different teaching and learning purposes. The review also suggests that crosscutting concepts are neglected among Asian-based STEM programmes and courses. This review characterized different STEM enactments in Asian secondary education, contributing towards identifying and discussing effective STEM programmes and strategies. Finally, this chapter points out areas for further development and invites researchers to further examine good practices in STEM education in the Asian context.

Keywords STEM studies · Asian classrooms · Primary school and secondary school · Pedagogical approaches in STEM studies · Student performance · STEM programme effectiveness

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Introduction

In recent years, especially in the second decade of the 21st Century, STEM education has gained more prominence in government policy and education circles in Asia. Concurrent with the global drive for STEM education, research in STEM education has shown exponential growth in the past decade. Much attention has been given to integrated STEM in recent STEM education research (Honey et al., 2014; Kelley & Knowles, 2016; Lee et al., 2019). Amongst the increased focus on integrated STEM, different challenges arising from its implementation have been documented such as the lesson enhancement or curriculum restructuring in the established discipline-based structure (Nadelson & Seifert, 2017), teacher preparation and professional development in STEM integration (Asghar et al., 2012; Lee et al., 2019), while one of the profound constraints for STEM teaching was teachers' lack of knowledge on embedding the four STEM components into the teaching of the subject (Kelley & Knowles, 2016). Research has also called attention to the need to better understand instructional practices and classroom operations due to a lack of empirical evidence of discerning elements crucial to the successful implementation of STEM education (Honey et al., 2014; Kang, 2019; Thibaut et al., 2018; Wahono et al., 2020).

Compared to the global STEM education scholarship, Asian-based STEM education studies are still in an emerging state, as Lee et al. (2019) highlighted that Asian-based STEM education studies comprised only 8.5% of the total examined international STEM education publications from 2013 to 2017 ($n = 665$), compared to around 65% from the United States. Thus, focusing on the Asian contexts, and with specific attention to the enactment of STEM education in Asian secondary schools, this chapter systematically reviews the enactment of STEM education with particular attention given to the nature and scope of STEM programmes or courses, instructional practices, and evidence reflecting the effectiveness of the instructional approaches in terms of students' learning.

Building a Framework for Reviewing STEM Programmes

There is in general a lack of consensus on how STEM education should be approached, largely due to the different experiences that involve different types of integration across STEM disciplines and school subjects (Sanders, 2009), or experiences that involve different forms, for example, single courses, school programmes, or extracurricular activities (Honey et al., 2014). A few recent studies have formulated different frameworks to describe the approaches and conditions of integrated STEM that most likely lead to positive outcomes of STEM education (Honey et al., 2014; Statauskiene & Mazgelyte, 2016; Thibaut et al., 2018). These frameworks provide useful references for reviewing a myriad of STEM programmes and courses implemented across Asian curriculum and classroom contexts.

Honey et al. (2014) developed a descriptive framework of integrated STEM education for a narrative review of 28 selected good practices in K-12 education in the United States. The descriptive framework identified four higher level features (and various illustrative subcomponents) of (1) goals (different statements of goals); (2) nature and scope (different types of STEM integration, disciplinary emphasis, duration, size); (3) outcomes (different outcomes in learning, schooling, and employment); and (4) implementation (different instructional designs, supports, partnership).

Second, in a European Commission-supported project, Statauskiene and Mazgelyte (2016) devised a top-down, theory-based four-dimensional framework to analyse 22 selected good practices in integrated STEM education with the aim of understanding the recurrent features of good practices in secondary schools across seven European countries. The framework integrated (1) learning theory (behaviourism, cognitivism, constructivism, humanism); (2) type of intellect (Gardner's multiple intelligences); (3) type of integration; and (4) competences (according to the European Reference Framework of Key Competences for lifelong learning).

Third, Thibaut et al.'s (2018) study reviewed 23 international STEM studies that provided a clear description of instructional practices for integrated STEM in secondary education. The study formulated, from the bottom-up, a five-principle framework, including (1) integration of content, (2) problem-centred learning, (3) inquiry-based learning, (4) design-based learning, and (5) cooperative learning.

With a specific focus on identifying features of STEM classroom practices and effective STEM programmes and strategies, components relating to the integration, implementation (of instructional practices), and the outcomes (of student learning) from the three integrated STEM education frameworks mentioned above are referenced in developing the framework for this review. Table 2.1 presents the framework formulated for this review. Features from Honey et al.'s (2014) descriptive framework provided the main structure of this review, and subcomponents from Honey et al. (2014) and Thibaut et al. (2018) were referenced to assist the illustrative procedure, which allows other subcomponents to be included in the review process.

Table 2.1 Framework for STEM programme review

Main features informed by Honey et al. (2014)	Subcomponents
Nature and scope of STEM programme integration	E.g. types of STEM connection and disciplinary emphasis; duration; size; formal or after-/out-of-school settings (see Honey et al., 2014)
Implementation of STEM programme: instructional practices	E.g. Problem-centred learning, project-based learning, problem-based learning, inquiry-based learning, design-based learning, cooperative learning (see Thibaut et al., 2018)
Outcomes of STEM programme for student learning	E.g. STEM literacy; 21st Century competences; interest, and engagement (see Honey et al., 2014)