A Comparison of STEM Education Status and Trends in Ten Highly Competitive Countries

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Abstract

This chapter summarizes the findings of STEM education from the 10 highly competitive countries in the previous chapters. A cross-country comparison is made concerning the aspects of STEM education background, current status, as well as the trends and issues. Several conclusions are generated as follows: (1) The supply and demand of the STEM-skilled workforce is unbalanced, with a shortage of STEM workers a common challenge for all of the countries. (2) Some countries have a decentralized schooling system wherein STEM curriculum and policy are under the jurisdiction of each state/ province/ territory; for the other countries with centralized systems, national curriculum guidelines for STEM have been published to guide teaching in all schools. (3) The strength of government influence on STEM education varies across countries. The central/federal government in some countries plays a dominant role in promoting K-12 STEM education, while the others lack direct control of local governments, leading to a heterogeneous landscape of STEM education around the country. (4) Many countries perform STEM education by means of teaching each STEM subject separately; besides, technology and engineering have been less emphasized than science and mathematics. (5) STEM education is usually embedded in traditional subjects (such as mathematics and science) from primary schools to upper secondary schools, with an exception in IE wherein integrated STEM is fully operated in preschools and primary schools. The STEM-focused VTE schools/programs and STEM programs in non-STEM-focused schools are more popular school types in formal education that emphasize STEM education. (6) All countries attach great importance to the STEM-related activities in non-formal education. They are delivered in the forms of STEM workshops, competitions, exhibitions, camps, seminars, school visits, and field trips by government-related organizations, schools, associations, NGOs, private companies, industries, museums, science centers, universities, and so on. (7) Students' STEM learning performance is measured by international and national assessments as well as by school-based tests. Overall, most countries perform well on science and mathematics literacy measures in PISA or TIMSS. In addition, boys tend to outperform girls on STEM learning assessments. (8) STEM teacher preparation programs are offered on a spectrum of integrative degree: at one extreme, teachers are trained as experts in one single field, and at the other, they are trained in trans-disciplinary programs. Overall, ongoing efforts raise an awareness of integrated STEM learning among STEM teachers. (9) STEM education reform is instigated prevalently by central government or sometimes local government. Most policy discussions concentrate on how to introduce the integrated STEM education into the classroom, or how to cooperate with various partnerships to enrich the diversity of STEM initiatives. (10) Major trends in STEM education include enhancing STEM teacher preparation, strengthening networks from outside of schools, increasing women's involvement in the STEM field, enhancing inclusive and integrated STEM environments, and so on. (11) Some issues these countries encounter include isolation of STEM subjects in schools, lack of qualified STEM teachers and teacher preparation programs, insufficient access to integrative STEM curriculums in school, lack of clear understanding of STEM, and so on.

Keywords: STEM education, comparative analysis, highly competitive countries

Introduction

This book compiles 10 country-specific reports, and each report illustrates the current status, issues, and trends of STEM education in its country. The countries listed in alphabetical order are: Canada (CN), Finland (FI), Germany (DE), Hong Kong SAR (HK), Ireland (IE), Singapore (SG), Sweden (SE), Taiwan (TW), the United Arab Emirates (UAE), and the United States of America (USA). They all were in the top 15 of the World Competitiveness Rankings published by the International Institute for Management Development (IMD) in 2021. These country reports provide a comprehensive picture of how STEM education has been implemented in these highly competitive countries.

This chapter presents a summary and international comparison of STEM education based on these country reports. Eleven comparison components are raised and discussed respectively. STEM here refers to the integration of Science, Technology, Engineering, and Mathematics into a transdisciplinary subject or course in K-12 schools. They can be offered on a continuum between the following two extremes: (1) Integrated STEM in which science inquiry, technological literacy, mathematical thinking and engineering design are interwoven in the classroom, and (2) Separated S. T. E. M. in which each subject is taught separately with the hope that the synthesis of disciplinary knowledge will be applied.

A Comparison of the STEM Education Background

This section compares the STEM education background of the 10 countries. The comparison is based on three components: supply and demand of a

STEM-skilled workforce, the schooling system, and the influence government exerts on STEM education in the 10 countries. Table 1 shows a summary of the comparison components for each country.

Comparison Component 1: Supply and Demand of STEM-skilled Workforce

According to the country's reports, all 10 countries agree that the STEM skills are vital for the fulfilment of a knowledge-based future, and recognize the importance of cultivating STEM talent for economic growth. However, it seems that a shortage of STEM workers is a common and significant challenge for all of the countries. Most countries mention that the gap between supply and demand of the STEM workforce is massive. The STEM-related job vacancies have been increasing largely, while the number of STEM graduates cannot keep pace with the skill demand. To face this challenge, the governments in most countries have expressed an eagerness to increase the number of STEM students and have implemented policies to attract more students to study STEM. In countries like SE, the number of people applying for STEM courses at university level is increasing, while in some countries (such as FI and the UAE), students' interest in STEM fields is diminishing gradually, with many students not choosing STEM fields.

Comparison Component 2: Schooling System

For the structure of the schooling system in the 10 countries, some countries with a federal system of government (such as CA, DE, and the USA) have a decentralized system of education wherein curricula and policy are under the jurisdiction of each state/ province/ territory. The other countries' governments (such as FI, HK, IE, SG, and TW) are more centralized, wherein national curriculum guidelines have been published to guide teachers' teaching in all schools, especially for the core/required courses in compulsory education. Generally, compulsory education in most countries covers from primary education to middle school or lower secondary education, lasting 9-10 years. A few cases have extended compulsory education upward to upper secondary education level (such as the USA) or have extended it downward to early education level (like FI). In addition, the education systems in countries such as FI, DE, IE, SG, TW, and the UAE have a dual-track feature in which there are separate high schools and colleges/ universities dedicated to technological and vocational education.

Comparison Component 3: Influence of Government on STEM Education

These highly competitive countries all agree with the importance of STEM education, while the strength of influence that each government exerts varies to some extent. In countries like the USA, TW, IE, and HK, the central/federal government plays a dominant and proactive role in promoting K-12 STEM education. For example, the USA treats STEM education as a priority and a national agenda wherein the Department of Education provides funding and resources. Also, the White House unveiled a STEM education strategic plan, detailing the federal government's strategy for expanding and improving the nation's capacity for STEM education. Besides government support for policies, strategies, or resources, the Department of Education in some countries (such as TW, IE, and HK) has developed national guidelines to promote the STEM education curriculum and partnerships between schools, teachers, and industries. The CN government, by contrast, allocates most of the federal funding to postsecondary education and research, while funding for K-12 STEM education is negligible. The central government in DE lacks direct control and influence on states; therefore, the STEM education landscape in Germany is quite heterogeneous.

Table 1 A summary of the supply and demand of a STEM-skilled workforce, schooling system, and influence of government on STEM education for the 10 countries

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
Supply and demand of a STEM-skilled workforce	1.There are current shortages of engineers, IT workers, healthcare specialists, and some tradespeople, especially electricians. 2.There is an economic demand for additional emphases on STEM. The demand for people who can fill STEM-related jobs will increase in Canada. 3.About 25% of postsecondary students are STEM majors, and government policies aim to increase this for economic purposes.	1.The technology industry will need 130,000 new STEM experts within 10 years, about 13,000 annually. 2.Students' interest in STEM fields diminishes gradually, with most students not choosing STEM fields.	1.A massive gap between supply and demand of the STEM workforce. 2.The gap in 2022 was 286,800 persons, 137% more than in 2021. There were around 477,600 STEM vacancies to be filled. The greatest bottleneck can be seen in the energy/electrical, machine/vehicle technology, IT, metalworking, and construction occupations. 3.The annual new supply of professionally qualified STEM workers will be significantly lower than the demographic replacement demand in the coming years.	1.Although the HKSAR Government has announced policies and measures to develop an Innovation and Technology (I&T) ecosystem, HK has been struggling hard to cultivate a critical mass of talent in the younger generation. There were only 6.6 researchers per thousand employments in 2018. 2.It is necessary to look for novel educational initiatives like STEM in HK primary and secondary education.	1.STEM skills are vital for the fulfilment of a knowledge-based future for Ireland. STEM education plays a role of supporting the development of Ireland's national STEM ecosystem. 2.Ireland produced either the highest or second highest proportion of graduates in STEM in the EU between 2014 and 2017. However, this is insufficient to keep pace with Ireland's STEM skills demand. 3.There were skill shortages in all STEM areas. 94% of engineering employers consider the shortage of experienced engineers to be a significant barrier to growth.	1.The economic growth of SG is largely reliant on STEM-related industrial sectors such as electronics, biomedical science, and precision engineering. 2.The key skills growth areas for the continued development of SG society and economy are related to the digital economy, green economy & care economy that are STEM-related. 3.SG STEM education continues to flourish for K-12 schools. 4.However, the % of STEM undergraduates & graduates has not reached the desired level for both males and females.	1.Sweden's STEM sector accounts for a large portion of its economy. 2.A significant proportion of the Swedish labor force is employed in areas such as the mechanical, manufacturing, construction, and information technology sectors, or other professional, scientific, or technical activities. 3.With the number of people applying for university level STEM courses in Sweden having increased over the years, there is a strong demand for a STEM-skilled workforce to maintain and continue Sweden's success in global markets. 4.The main areas related to the STEM labor force demand include economics, engineering, forestry, science and health, and education.	1.The proportion of STEM talent shortage reached 63.5% of the total need in 2020, mainly including the information technology, science, statistics, and engineering fields. 2.The government has expressed an eagerness to improve the number of STEM professionals and enhance Taiwan's international competitiveness through education.	1.To diversify and strengthen the rising oil-based economy, the UAE has begun revamping its education system, particularly the STEM subjects. 2.Compared to other Middle East countries, the UAE is not a leading contributor to technology and science development. The UAE educational system needs to evolve and provide highly talented STEM workers to reach its vision of becoming an innovative and self-sustaining economy. 3.There is a reducing trend of STEM in the UAE. It is not certain that students will enroll and major in STEM fields and will become productive and innovative members of STEM professions due to many challenges and barriers influencing students' choice to study for further education and for future career aspirations.	1.There is a shortage of STEM workers. Between 2020 and 2030, the U.S. jobs in STEM are expected to grow 10.5% (to more than 11 million) which is 1.4 times faster than non-STEM occupations (7.5%). 2.The annual median salary for STEM degree graduates is 2 times higher than those who graduate in a non-STEM occupation. 3.The STEM workforce represented 23% of the total U.S. workforce in 2019. 4.Over half of the STEM workers don't have a bachelor's degree and work primarily in health care, construction trades, installation, maintenance and repair, and production occupations.

Table 1 (continued)

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
Schooling system	1.Decentralized system of education, wherein curriculum and policy are under jurisdiction of each province and territory. 2.K-12+ STEM education in CA includes elementary, secondary, and tertiary or postsecondary education levels.	1.Education services from pre-school education to higher education are free of charge. Great emphasis on equality and justice concepts. 2.Compulsory education: early childhood education (1 year), primary education (6 years, lower secondary/ middle school 3 years, upper secondary/ high school or vocational school 3 years; years 6 - 19). 3.After lower secondary education: common/ vocational high schools (3 years). 4.Higher education: applied universities and traditional research universities.	1.The Federal Republic of Germany consists of 16 federal states that have their own education ministries operating independently. Even though some minor differences exist, these educational systems are comparable and can be described as one system. 2.Eight ISCED levels are divided into five main education levels: elementary, primary, lower secondary, upper secondary and tertiary education.	The HK education system includes K (kindergarten, 3 years), Key stage 1-2 (primary education, 6 years), Key stage 3-4 (secondary, 6 years), 18+ (post-secondary, 4 years), and post-graduate level.	1.Ireland's compulsory schooling system covers students from age 7/8 to 15/16, including primary, junior cycle, and senior cycle programs. 2.Irish preschools are generally run by private organizations, supported by government funding. 3.All public and private primary schools follow the same national curriculum. 4.The post-primary school landscape is comprised of voluntary secondary schools, community schools, and comprehensive schools; over time, the separation of academic and vocational focus has become less apparent.	1.Preschool is not compulsory but all must attend a national primary school. 2.Primary school (6 years), secondary (4-5 years), & pre-university (2-3 years)/ polytechnic. 3.There are multiple educational pathways (tracks) after primary school: IP, Express, Normal (Academic & Technical) courses. 4.All tracks present opportunities to pursue a university course of study. Opportunities to study science and math are available at every grade level.	Schooling system includes: 1.Preschool, ages ≈ 6-7 2.Compulsory school, ages ≈ 7-16, with 3 stages: primary school (grades 1-3), middle school (grades 4-6), and high school (grades 7-9) 3.Upper secondary school, ages ≈ 16-19 4.Higher education: diplomas/bachelor, master, licentiate and doctoral degrees	1.A 6-3-3-4 education system, including stages of elementary school, middle school, upper secondary school (general and technical high schools), and college/university education. 2.A 12-year basic education is offered and grades 1 to 9 are compulsory education.	1.The transition between the educational phrases has been rapid. Cycle 2 and cycle 3 enrollment between 1973 to 2009 rose from 22% to 93%. 2.In the 1970s, 48% of adults were illiterate and 40 years later, over 93% are literate. 3.The UAE education system is going through a period of remarkable educational reforms. Through UNESCO and the OECD, the UAE is pursing global education reforms to enhance the quality and access to education in public and private schools.	1.K-12 schooling is primarily achieved through public education, while there are some alternatives, such as private schools, home schooling, and charter schools. 2.Public education is free and compulsory; students' dropout age varies (between 14-18 years of age) by state. 3.Secondary education typically includes a middle/ junior high school and a high school experience. 4.After high school, students can enroll in a community college, college or university.

Table 1 (continued)

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
Influence of government on STEM education	1.Federal, provincial, and territorial governments have been active in the STEM education policy context. The federal government has 31 initiatives of STEM education, while most are not K-12 school-based. 2.The large bulk of federal STEM funding is for postsecondary education and research, while a negligible fraction is allocated to K-12 STEM education. 3.The federal government prioritizes informal STEM education initiatives, like extra- curricular local and national STEM competitions.	1.The Government supports for STEM-related projects, such as The LUMA-SUOMI project were assisted by the Ministry of Education and Culture. 2.In-service education for teachers is free of charge and funded by the municipalities or National Agency of Education; The LUMA FIN-LAND program was also supported by the Finnish Ministry of Education and Culture.	1.The competence to exert influence on school education is distributed to Germany's government, the federal states' governments, local authorities and the schools. - Just a few policies on quite an abstract level come from the central government. - Many policies are created by the state's governments, for instance the regulations about school subjects and subject-specific teaching quantity. - Many decisions at the executive level are made by the schools. 2.In general, Germany's central government has limited influence on the education system due to the fact that responsibility to regulate the specific education policies is given to the 16 states.	1.The HKSAR Government plays a dominant role in developing STEM education in schools through enacting policy and appropriating funding, resource and support. 2.STEM is considered as a measure to equip future generations for the keen global competition ahead in HK. 3.HK government promotes and starts STEM early in primary and secondary schools to narrow the talent gap.	1.The strategic direction of developing STEM education is heavily supported and influenced by governmental incentive and funding. 2.The Irish Government is proactive in developing the STEM strategy with the agenda of providing the best education and training in Europe by 2026. 3.The Department of Education and Skills has developed guidelines to support STEM education partnerships between schools, school leaders, teachers, and industry.	1.The academic syllabus in national schools is decided by the MOE. 2.The curriculum review cycles take place once every 6 years, involving experts from MOE, schools, institutes of higher learning (IHLs) & industries. 3.The government's support, mandate, and influence for STEM education takes the form of resource allocation, policy documents & expertise availability.	1.The government has overall responsibility for higher education with funding allocation being a dominant way of having impact. It has been providing extra funding to higher education institutions for teacher education programs since 2015. 2.The Riksdag (the Swedish national legislature or parliament) and the government are responsible for the curriculum and what pupils learn in school. 3.The compulsory school curriculum written by the Swedish National Agency for Education is cohesive in that all students follow the same curriculum and all subjects offered are mandatory.	1.The latest nationwide 12-year basic education curriculum guidelines treat STEM as an interdisciplinary education and allocate it to the technology domain of the upper secondary education stage. 2.For STEM-related departments in higher education, MOE policies focus on expanding enrollment by 10-15%, diminishing the restriction on the teacher-student ratio, and encouraging the offering of interdisciplinary programs. 3.The government supports setting up 100 Maker and Technology Centers to design STEM-related activities and provide the modules to K-12 teachers. 4.Informal STEM activities (such as camps & competitions) are highly supported by the government.	1.The goals of STEM education are reflected in the main government's reform agendas (such as UAE Vision 2021) and the related published studies. 2.The MOE implemented the educational development program for math and science as part of improving the integrated STEM education. 3.The MOE has signed a 7-year deal with the American company McGraw-Hill Education to procure all K-12 math and science instructional materials in e-book and print formats.	1.STEM education is a national agenda item. The U.S. Department of Education provides a variety of resources, including funding opportunities, relevant and timely information about STEM. 2.STEM education became a priority for the U.S. when The White House (2018) released The STEM Education Strategic Plan, Charting a Course for Success: America's Strategy for STEM Education.

A Comparison of the Status of STEM Education

This section presents a comparison of the current STEM education in K-12 schools for the 10 countries. It comprises six comparative components, namely: contexts of STEM education, STEM education system/ framework, STEM-related activities in non-formal education, STEM learning assessment and career development, STEM teacher qualification and professional training, and current STEM education reform and policy discussions. Table 2 shows the summarized information of each country for the above-mentioned components.

Comparison Component 4: Contexts of STEM Education

The STEM current practices in schools, key statistics, and highlights of policies and strategies in the 10 countries are discussed here. Since traditional education systems prefer a monodisciplinary approach, it is observed that many countries perform STEM education by means of teaching each subject of S.T.E.M. separately. Among these four subjects, mathematics and science are typical core subjects that are commonly included in the curriculum from primary schools to secondary schools. By contrast, the subjects of technology and engineering are not so prevalent, and fewer efforts have been concentrated on them. Some countries, such as DE, CN, SG, and the UAE, are examples of the separated STEM education approach. Even though monodisciplinary teaching is popular in secondary education, a number of countries (e.g., FI and IE) highly promote the interdisciplinary or transdisciplinary approach. Taking FI as an example; the latest national core curriculum emphasizes the learning of transversal STEM competences through the phenomenon-based teaching and learning approach which has a transdisciplinary nature.

As for the proportion of students in STEM fields, some countries, such as FI, DE, SG, and TW, have more than one-third of students in STEM postsecondary education. DE even has the highest rate of 1st year students in STEM in an international comparison. Compared to males, females are underrepresented in STEM fields in most countries.

The prioritization of STEM education is apparent from the government's policy or strategies in FI, HK, IE, TW, and the USA. For example, the USA has developed international/ national educational standards in each of the STEM disciplines. Thus, states could build up their own STEM programs and curricula based on the standards. Ireland is another case where its government is proactive in developing a STEM strategy with the agenda of providing the best STEM education and training in Europe. On the other hand, Canadian federal policies and funding have little effect on K-12 STEM education, and the UAE is just at the early implementation stage of STEM education and is calling for an integrated framework suitable for K-12 schools.

Comparison Component 5: STEM Education System/Framework

This part focuses on discussion of the goals of STEM education, types of K-12 schools offering STEM education, and school categories especially emphasizing STEM education in formal education. For the goals of STEM education, a number of countries (such as the USA, FI, HK, and IE) have set up clear goals for STEM education in formal documents. For example, in the USA, there are three broad goals for STEM education, that is, building strong foundations for STEM literacy, increasing diversity, equity, and inclusion in STEM, and preparing the STEM workforce for the future. Similarly, HK's STEM education aims to cultivate students' interests and solid knowledge in STEM, to strengthen integrated ability to apply knowledge and skills across different disciplines, and to nurture innovative talents for the needs of the 21st century. On the other hand, Germany has no fixed objectives for STEM education, because traditionally STEM is not a subject in schools. In Taiwan, explicit goals of STEM education have not been generated yet, due to the inconsistencies between policy makers and practices of STEM education.

In terms of types of K-12 schools offering STEM education, it is observed that STEM education is usually embedded in several subjects from primary schools to upper secondary schools. Specifically, STEM is predominantly taught in the traditional subjects of mathematics or science (biology, physics, or chemistry) separately. An exception is IE wherein integrated STEM is fully operated in preschools and primary schools. In addition, mathematics and science are usually mandatory in compulsory education, and more optional courses about science, technology, engineering, or STEM-related subjects are offered as students move to higher educational levels. It is worth noting that STEM education in a few countries is not common in regular classrooms. One example is DE, where STEM education is often offered as voluntary classes or extracurricular activities; the other is the UAE, where all integrated STEM education initiatives are exclusive to private educational institutions in which international curricula with parts of STEM education are operated.

The National Academy of Sciences (2011) in the USA identified four school categories in formal education that emphasize STEM education, namely elite STEM-focused schools, inclusive STEM-focused schools, STEM-focused vocational and technical education (VTE) schools or programs, and STEM programs in non-STEM-focused schools. Among the 10 highly competitive countries, the STEM-focused VTE schools or programs and STEM programs in non-STEM-focused schools are more popular, while the other two categories are uncommon. In countries where vocational education sectors are prominent (such as DE, SG, TW), there are many VTE schools or programs at the upper secondary education level that are designed to prepare students for a broad range of STEM careers. As for STEM programs in non-STEM-focused schools, they are often provided in countries where comprehensive high schools are prevalent (such as the USA). Many of these schools offer advanced coursework through the Advanced Placement (AP), International Baccalaureate (IB) programs, and other opportunities for highly STEM motivated students.

Comparison Component 6: STEM-related Activities in Non-formal Education

All countries in this comparison attach great importance to the STEM-related activities in non-formal education, no matter how many efforts they have made in formal education. Such activities are provided through diverse forms, including STEM workshops, competitions, exhibitions, summer/ student/ maker camps, seminars, school visits, field trips, and so on. Most of them are offered after class time or out of schools by government-related organizations/ schools, private cram schools, associations, NGOs, private companies, industries, museums, science centers, universities, and so on. Among them, museums are one of the most popular ways to access STEM. For example, museums in Sweden offer a wide variety of exhibitions, workshops tailored for schools, school visits, and competitions to enrich students' STEM learning experience.

Comparison Component 7: STEM Learning Assessment and Career Development

Students' STEM learning performance in the 10 countries is commonly measured by international assessments as well as by national or school-based tests in each country. On the whole, most countries perform well on science and mathematics literacy measures in PISA or TIMSS. Some countries' scores are even ranked at the top of all participants (such as FI, HK, IE, SG, TW, etc.), or achieve the supreme level in their regions. Finnish and Irish students are noted to perform highly in math and science with respect to EU countries, as do the HK, SG and TW students in the Asian area. As for the gender difference, boys tend to have higher scores in mathematics and science measures than girls, while in two Nordic countries, FI and SE, girls outperform boys, and the gap is even significant in FI. In the USA, although K-12 students do not perform that well as compared with peers from around the world, the USA has some of the best STEM-related programs in higher education that cultivate a great number of talents in STEM fields. It is worth noticing that only mathematics and science literacy are measured in PISA or TIMSS; no valid international measures are issued to assess students' learning performance in technology and engineering.

In addition to joining the international assessments, some countries hold national assessments in the form of standardized tests, proficiency tests, or surveys. For example, the Institute for Quality Development in Education in DE regularly conducts a nationwide survey to assess fourth and ninth graders' performance in science and math, and the results are reported in comparison to KMK standards. Similarly, there are national standardized tests (GCE and PSLE) in SG to evaluate students' performance. In the USA, the National Assessment of Educational Progress (NAEP) is developed to measure student achievement nationally and periodically. It covers not only mathematics and science, but also technology and engineering literacy in STEM fields; the results are presented in "The Nation's Report Card" for stakeholders to access.

Regarding students' STEM career development, some countries have special emphases on students' vertical articulation to post-secondary STEM-related programs or horizontal transition to STEM-related workplaces. For example, science and engineering careers are a part of STEM education in FI. In HK, after the junior secondary level, students have many paths for STEM career development, such as opting for STEM-related elective subjects, taking career-oriented "Applied Learning Courses," choosing STEM-related undergraduate courses in universities, and so on. In SG, students have to study and meet minimum grade requirements at the secondary school and junior college levels to further pursue a STEM course at tertiary level. For countries with a vocational education system at the secondary education level (such as DE, TW), students in STEM programs usually have internship or apprenticeship opportunities to prepare them for a specific type of job, while meeting the STEM-related industry's need for highly skilled employees.

Comparison Component 8: STEM Teacher Qualification and Professional Training

Because some countries treat S.T.E.M. as monodisciplinary subjects and the others treat it as a transdisciplinary subject, STEM teacher preparation programs are offered on a spectrum in terms of the degree of integration. At one extreme, STEM remains as distinct and disjointed subjects wherein teachers are trained as experts in one single field. Taking CN, HK, and the UAE as examples, neither STEM teacher qualification requirements nor STEM-majored pre-service programs are offered. Teachers obtain most of their STEM teaching competencies through in-service training activities or from their own experiences. At the other extreme, STEM teachers are well trained in an intradisciplinary or transdisciplinary manner and programs. For example, secondary education teachers in FI are trained in joint programs provided by the faculty of science and education together. In DE, general education teacher programs require studies on two or three subjects and pedagogy training. As for vocational teachers' training, one general education subject has to be studied besides one vocational subject. Further, Taiwan provides three types of integrative/interdisciplinary STEM teacher education preparations or in-service trainings: degree programs in master and doctoral degrees, certificate or diploma programs for pre- and in-service teachers; and short-term training programs, courses, or workshops for in-service teachers. Overall, ongoing efforts have raised awareness of integrated STEM learning among STEM teachers in these 10 countries.

Comparison Component 9: Current STEM Education Reforms and Policy Discussions

In recent years, STEM education reform occurs prevalently from either central government or local government in these countries. In addition, policy discussions often concentrate on how to introduce the integrated STEM education into the classrooms or through out-of-school activities, how to support and cooperate with various partnerships to enrich the diversity of STEM initiatives, and so on. For example, the White House in the USA has set out federal strategies for a future that all Americans will have lifelong access to high quality STEM education. Besides the efforts from federal government, a number of professional associations and nonprofit organizations (such as ITEEA, Battelle for Kids, etc.) have been involved in the development of standards for STEM literacy and have illustrated the framework of skills and knowledge students need to succeed in work and life. Similarly, after extensive consultation with stakeholders, the Department of Education in IE has published a STEM Education Policy Statement that focuses on the many strengths in STEM education while providing a roadmap to address the areas for development. Four main pillars are identified as follows: increased success in STEM, including: nurturing learner engagement, enhancing early years practitioner and teacher capacity, supporting STEM education practice, and using evidence to support STEM education. In countries such as SE, TW, SG, and IE, recent curriculum reform has taken STEM education into consideration. Take SE as an example; a clear direction of STEM education is indicated in the curriculum in which one significant change is to introduce programming and safety of the use of technology in mathematics and technology subjects. In TW, more opportunities to implement integrative STEM education were provided in the school-based curriculum in the last curriculum reform.

Among these countries, FI is the only one where STEM education has been mainstreamed in the education system and reached high consensus from the stakeholders; therefore, STEM issues are not a matter of debate there. By contrast, the German system in general is quite static and traditional. Any change including integrative STEM education needs a considerable amount of time.

Table 2 A summary of the status of STEM education for the 10 countries

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
Contexts of STEM education	1.STEM is found to be a catalyst for economic and cultural change; however, federal policies and funding for K-12 STEM education has little effect on practices in schools and teacher education. 2.Most efforts have been concentrated on math and science. Engineering education is excluded from K-12. The ITEEA Standards for Technological and Engineering Literacy is the first step to promote TE in K-12 STEM education. 3.Women are underrepresented in STEM postsecondary education: only 22% in engineering, 30% in math and computer science, 32% in physical sciences, and 60% in biological sciences. 4.About 50% of STEM postsecondary students are immigrants. 5.46% of Canadian youth anticipate working in a STEM career.	1.Diverse national level STEM education development projects are conducted, such as LUMA-SUOMI, StarT development project, LUMA FINLAND program, the "Co4-Lab" project, etc. 2.Several networks aim to improve students' and teachers' knowledge and skills in STEM fields, such as LUMA and Innokas networks. 3.National core curriculum emphasizes STEM competences. Learning transversal competencies is a major part of STEM education. 4.The phenomenon-based approach to STEM education is proposed. In primary education, the transdisciplinary approach is a major teaching method in STEM. In secondary education, STEM subjects are taught separately. 5.Around 36% of all students studied STEM in universities; the percentage in applied universities was 34%.	1.Highly focused on traditional subjects (like math, biology, physics & chemistry); only math is taught in each school and has educational standards in each level. That is, STEM-relevant subjects (like computer science, technology) are lacking. 2.In an international comparison, Germany has the highest rate of 1st year students in STEM subjects; 36% obtained a tertiary degree in STEM subjects compared to 24% in OECD countries. 3.In general, Germany has an above-average # of young people starting STEM studies, and the proportion of women is increasing slightly, while the high # of dropouts continues to be a challenge.	1.Policy documents announce the positioning of STEM education in HK indicating the promotion of STEM education is a key emphasis under the ongoing renewal of the school curriculum. 2.The "Final Report" from the Task Force on review of the school curriculum suggests setting up a designated committee at policy level, to appoint STEM coordinators, and to provide central guidelines for schools. 3.Surveys & study findings revealed concerns over the shortage of STEM teachers & inadequate training, availability of professional development of STEM education, etc. 4.Around 65 to 80% of the primary and secondary schools have implemented STEM education.	1.The prioritization of STEM education in Ireland is apparent from government policy. 2.The STEM Eco-System aligns with and complements formal and informal STEM education. Core curricular objectives are explicit and progressive with a clear focus on the integrated nature of STEM activity and the value of interdisciplinary capacity. 3.The "Innovation 2020" strategy for research and development, science, and technology highlights the critical role that STEM education plays in ensuring the continual development of a talent pipeline to support the foreign direct investment and an active ecosystem for indigenous tech start-ups.	1.K-12 STEM education is carried out in a monodisciplinary manner, where science, math, design and technology & computing are taught as separate subjects by different teachers. It works well with high levels of proficiency. 2.The conversations among educators and policy makers about integrated STEM learning started in 2019 and are still ongoing. 3.Around 58% of polytechnic students take STEM-related courses in post-secondary schools in 2020; the percentage in ITE is 62%, and 47% for university.	1.86% of Swedish 1- to 5-year-olds attend preschools that offer a national curriculum embracing a holistic inter-disciplinary approach. 2.The upper secondary education providers offer 18 national programs across 2 strands: a vocational strand and a higher education preparatory strand. Among the programs, the STEM direct-related programs (Natural Science and Technology) accounted for 21.2% of upper secondary level students in 2021. 3.As for a crude classification, about 42.2% of upper secondary level students were in STEM related programs.	1.The government has emphasized STEM education for all education levels to deal with the insufficiency of STEM talents. 2.Engineering design and interdisciplinary STEM education have been addressed at upper secondary schools, while the main ideas still focus on technology education. 3.Some local education bureaus have started to exert their policies of STEM education. 4.There is a lack of systematic organization for STEM education in basic education. 5.The number of students in STEM has declined from 35.4% to 31.8% over the past decade. 6.There is a low proportion of females majoring in STEM: 15% in science, 28% in technology, 30% in engineering, & 32% in math.	1.The implementation of STEM is at the early stage in the UAE and there are calls for an integrated framework for effective implementation in K-12 education. 2.STEM education has been introduced formally and informally in UAE education over the past few years with light focus and coverage. 3.Engineer is ranked as the top preferred job (15.9%) by Emirati youth.	1.No national curriculum for STEM education, while there are international/national educational standards in each of the STEM disciplines for states to build their own STEM programs and curricula. 2.There are a few notable national curriculum programs that focus on STEM education, such as Project Lead The Way (PLTW), ITEEA's Engineering by Design (EbD), Engineering is Elementary (EiE), etc.

Table 2 (continued)

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
STEM education system/ framework	1.Elementary schools are somewhat inter- or trans-disciplinary. 2.Nearly all public secondary schools have isolated math and science and some form of technology courses, but no engineering requirements. 3.Very few technical (vocational) secondary schools are specific to the T in STEM and specialize in functional integration or applications of math and science. In the early 2000s, they had reconfigured into Career Technical Centers. Later, since priorities shifted to grant "polytechnic" institutions later, it has been ineffective in providing alternatives to comprehensive high school for STEM immersion.	1.Goals for STEM education in lower secondary/ middle school are analyzed in terms of aims for math, biology, craft, chemistry & physics, as designated in the National Core Curriculum. 2.The middle school STEM-oriented curriculum is part of the curriculum of different school subjects. STEM literacy in the Finnish middle school is grouped under 3 areas: attitudes, knowledge, and STEM practices. 3.Science and engineering process skills introduced in the curricula require the concretion of science with math, engineering, & technology. 4.The subject-specific curriculum emphasizes students' engagement in science inquiry and technology-related problems. 5.The middle school curriculum emphasizes the learning of transversal competencies.	1.Due to the German tradition, STEM isn't a subject in schools and has no fixed key objectives for STEM education. 2.Some pragmatic goals of STEM education are identified: to supply the economy with a STEM workforce, to integrate school-external learning occasions, to take real-life problems into account without the restrictions of curricular settings. 3.A practice-oriented learning style is conducted that addresses real-life problems and situation. 4.Since there is no uniform, didactic concept for integrated STEM education, it is difficult to implement integrated STEM into regular classes. It is often offered outside the compulsory lessons as voluntary classes or an extra-curricular offer. 5.STEM is taught as separate subjects in ISCED levels 1 to 3. 6.In the vocational school sector, there are many schools that focus on STEM topics.	1.HK's STEM education aims to: 1. cultivate students' interest in science, technology and math; and develop among them a solid knowledge base; 2. strengthen ability to integrate and apply knowledge and skills across different STEM disciplines; 3. nurture creativity, collaboration and problem solving skills; and foster innovation and entrepreneurial spirit as required in the 21st century. 2.The scope of implementing the curriculum change of STEM education covers all primary though General Studies and the 3 STEM KLAs in secondary schools. In senior secondary school, STEM learning is offered to those who opt for STEM-related subjects. 3.STEM education depends on the readiness of teachers and schools. It varies among schools.	1.The national STEM education policy sets out a goal of providing "…the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behavior, confidence, and persistence, along with the excitement of collaborative innovation". 2.Types of K-12 schools offering STEM education: preschool and primary schools (fully integrated STEM); junior cycle (different subjects, including math, science, & 4 technology subjects: material technology wood, engineering, applied technology & graphics); senior cycle (separate STEM subjects; except for math, the other subjects are elective).	1.At primary schools, fundamental learning of math from grades 1 to 6, and science from grades 3 to 6. 2.For secondary 1 & 2, science & math are mandatory. At the secondary 3 & 4, different science subjects are offered for choice, and elementary math is required. The Applied Learning Programme (ALP) is available in all secondary schools which emphasizes the applications of knowledge and skills learnt in schools to problems in industries and society. 41% of schools have STEM-related ALP. 3.Advanced learning of math and science is offered at junior colleges; ITE provides a curriculum aimed at the acquisition of practical STEM-related skills. 4.Polytechnics train professionals to support the technological and economic development. Universities have programs to develop top talents in S.T.E.M.	1.There is a national curriculum for preschools and compulsory schools. In the pre-school curriculum, some areas are close to STEM, such as "creative and aesthetic forms of expression," "mathematical reasoning and forms of expression," etc. 2.In compulsory schools, STEM education is embedded in several subjects, however it is predominantly in "the traditional" STEM subjects of math, technology, crafts and the science subjects (biology, physics, and chemistry) which are all mandatory from grade 1 to grade 9. 3.Of the 6,890 total guaranteed hours of compulsory school, 34.25% are directly related to STEM subjects, and there is more STEM-related content in other subjects, such as physical education and health, history and geography.	1.STEM education goals (generated from survey and literature review): cultivating students' 21st-century skills, STEM literacy, and capabilities in interdisciplinary problem-solving. 2.In the 12-year basic education, STEM-related activities generally take place in school-developed curricula (in 'alternative curricula' for primary and middle schools/ 'alternative learning periods' for upper secondary schools). 3.Teachers have limited knowledge in creating STEM activities; thus, 'Maker and Technology Centers' help to develop STEM modules for teaching. Also, MOST has encouraged the development of school-orientated STEM activities, like Mushroom experiment, Incubators design, Mousetrap car, Bridge design, Seismic structure design, etc.	1.All integrated STEM education initiatives are exclusive to private educational institutions, as they are based on international curricula and accreditations in which STEM education is recognized as a part of curricula. 2.The government is taking logical steps to expand integrated STEM education to public schools. 3.A 3-pronged structure provides a history of how the current STEM subject integration approach to education has occurred, including design-based education, project-based education, and subject integration.	1.Three broad goals for STEM education: building strong foundations for STEM literacy; increasing diversity, equity, and inclusion in STEM; preparing the STEM workforce for the future. 2.Some high schools focus on STEM education. Also, students can enroll in competency-based career and technical education (CTE) programs and receive specialized training in a STEM-related field. 3.High school graduates can enroll in a community college, or university that offers STEM-related degrees.

Table 2 (continued)

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab \ Emirates (UAE)	United States of America (USA)
STEM-related activities in non-formal education	1.In 2018, the government launched the “Future Skills” initiative; a few projects directly linked to K-12 school systems, like “STEM Skills and an Innovation Mindset for Youth” project. 2.The Canada Agriculture and Food Museum, Aviation and Space Museum, and Science and Technology Museum offer sensory experiences that immerse both young and old in the many ways science and technology intersect with Canadians’ daily lives. 3.The Geering Up program immerses children, youth, and teachers in summer STEM camps to investigate engineering, science, and technology in a fun, safe, & educational environment.	1.Entrepreneurship education: such as the “Me & MyCity" project, the "Economic Information Office” and "Federation of Finnish Enterprises” website, etc. 2.Student Camps: to improve and strengthen the science, math, and technology interests of the participants. 3.Cultural Events (festivals, competitions, TV series, etc.): to draw students’ interest in science and technology. 4.Science Centers: such as the Heureka center offers entertaining, exploratory, and pleasant learning experiences for visitors of all ages in the science, math, and technology fields. 5.Museums: such as Museum of Technology, Design Museum, Zoology museum, The Natural History Museum, etc.	1.Many STEM initiatives/ programs that bring the stakeholders are provided at the local level. 2.At the national level, there are some STEM-related programs supported by BMBF. For example: - A central action plan for STEM (2019) aims to strengthen STEM education across the board through extracurricular offerings for children and young people. - The "Let’s do STEM" initiative informs and inspires girls and young women about STEM courses. - The "Youth Research" competition aims to get young people interested in STEM. - The foundation “House of Little Scientists” is committed to early education in the STEM field in daycare centers and primary schools. - The “MINT-EC” initiative is dedicated to promoting STEM talents.	1.Numerous out-of-school activities provided by government-related organizations and schools, NGOs and private companies, including competitions, exhibitions, talks, workshops, courses, field trips and camps. Workshops and courses combined take up over 80% of the total number and most activities related to the science subject. 3.The faculties of science and engineering of local universities organized STEM education summer programs for secondary students. 4.Associations of different subject disciplines organize IT workshops, seminars, competitions, sharing, exhibitions and exchange-tours for teachers and students.	Extra-curricular activities consisting of STEM-related activities such as summer STEM camps, workshops, or competitions in non-formal education.	1.Co-curricular activities after class time. 2.Three government affiliated organizations play crucial roles: (1)Science Centre Singapore (STEM Inc.) offers STEM workshops for students and teachers, and runs various award programs that make STEM ideas and knowledge accessible to the masses. (2)A*STAR offers attachment programs and scholarship programs to nurture young scientific talents. (3)IMDA develops and regulates the infocomm and media sectors to create opportunities for growth in STEM talents. 3.Private companies, industries, and non-government organizations offer STEM- related programs, holiday camps, enrichment classes, attachments, etc.	1.There are many informal STEM activities for young people and many are not organized by a centralized system; for example, individual people can and have organized ad-hoc STEM-related summer camps. 2.One way to access STEM is through museums that offer a wide variety of exhibitions, workshops tailored for schools, school visiting (such as mobile maker tours) and competitions. 3.For the higher education level, House of Science is a resource developed by KTH Royal Institute of Technology and Stockholm University with an aim of increasing students’ knowledge of and interest in STEM. Around 100 STEM related programs are provided for compulsory school students in which students can work with researchers on a group project. 4.There are many STEM-related summer camps offered to school students.	1.An increasing number of STEM activities provided by the government, educational institutions or associations, and private cram schools, such as: Maker camps, Annual National Technology Competition, GoSTEAM competition, Start! AI Car competition, etc. 2.STEM aids developed by publishers enrich young children’s STEM experience. 3.Exhibitions of multiple STEM themes in museums offer students STEM learning experiences from non-formal access.	1.STEAM workshops run by experts with an emphasis on projects. 2.The STEM and STEAM fields are more appropriately taught through projects such as STEAM yardstick activities and visiting sustainability pavilions at Dubai Expo 2020.	Most states recognize the importance of STEM and have developed websites providing resources or set up centers to support STEM education via offering grants, events, activities, competitions, etc. (such as the STEM Action Center in Utah).

Table 2 (continued)

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STEM learning assessment and career development	1.Most Canadian students perform well enough on measures in PISA of reading, math, and science proficiency, and in TIMSS. 2.Most 8th graders achieved average results on the Pan-Canadian Assessment Program. 3.No measures of performance in engineering and technology education.	1.The number of studies in the STEM subjects in Finland is higher than in most countries in Europe. 2.Finnish students' PISA performances are ranked among the top 5 countries in the OECD. The performance gap between girls and boys is the largest across OECD countries; girls have higher scores in math and science than boys. 3.Finnish 4th graders performed the best in TIMSS among the Nordic countries. 4.The emphasis on science and engineering careers is a part of STEM education.	1.The Institute for Quality Development in Education regularly conducts a nationwide survey of achievement levels in specific areas. Nearly 45% of 9th graders and 62% of 4th graders met or exceeded the KMK standards in math, respectively. More than half of the 9th graders met or exceeded the standards in nature science subjects. 2.In PISA 2018, German 15-year-old students had better competencies in math and science than the OECD average. 3.In TIMSS 2019, Germany is above the international average in math competencies of 4th graders.	1.Hong Kong students' performance in PISA has declined; ranking in science competence fell from 2nd in 2006 to 9th in 2018, and the percentage of "high-achievers" decreased by 8.1%. 2.After junior secondary levels, students have many paths for STEM career development, such as opting for STEM-related elective subjects, taking a career oriented "Applied Learning course", choosing STEM related undergrad courses in university. However, the actual figures of students taking them is challenging. 3.Around 34% to 36% of students graduated from the University Grants Committee funded STEM-related undergrad courses, while they failed to attract students with the best academic results.	1.Through TIMSS & PISA, Irish students' math and science are noted to perform highly with respect to other OECD & EU countries. (1)In TIMSS 2019, there are 7 countries above, 4 similar, and 46 below the performance of Irish pupils in math; and 12 countries above, 12 similar, and 33 below Irish pupil performance in science at the 4th grade. (2)In PISA 2018, Ireland was ranked 16th of the 37 OECD countries, and 21st of the 78 participating countries in math; and ranked 17th of 37 OECD countries and 22nd from 78 participating countries in science. 2.There is a narrowing of the gender gap in math, with male mean scores were only slightly higher than female scores.	1.Assessment is through students' results from school-based tests, examinations, national standardized tests (like GCE, PSLE), or IB. 2.For PISA 2018, 93% of students attained a level 2 or higher for math, higher than the OECD average of 76%; 37% of students at a level 5 or higher, compared to 11% for the OECD average. For science, 91% of students attained a level 2 or higher, compared to 78% for the OECD average; 21% of students scored at level 5 or 6, while 7% for the OECD average. 3.To pursue a STEM course at tertiary level, students must meet minimum grade requirements at the secondary school and junior college levels.	1.There are national test in math (for year 3, 6, 9 students) and biology, physics, or chemistry (for year 9 students), while there are no national tests in technology and crafts. Girls tend to outperform boys in all subjects. 2.In PISA 2018, Swedish students scored higher than average in reading, math, and science. 3.Similarly, Sweden tends to perform above the average in math and science in TIMSS. 4.Many Swedish students pursue STEM-related professional degrees. The most in-demand programs were those leading to MSc qualifications in engineering fields.	1.Taiwan students performed well in PISA & TIMSS. In PISA 2018, students ranked 5th in math and 10th in science (out of 79 countries). In TIMSS 2019, the 4th graders' math & science ranked 4th and 5th (out of 58 countries); the 8th graders ranked 2nd (out of 39 ones) for math & science. 2.A worldwide assessment for STEM performance has not yet been developed. To fill the gap, a NTNU STEM research team has been working on a context-based STEM competency online assessment to assess students' performance in interdisciplinary problem-solving competency.	1.In 2016, the UAE achieved the highest score amongst all Arab countries in the PIRLS. 2.In 2021, the targets for average TIMSS scores and average PISA scores were to be among the top 15 and 20 countries respectively. 3.On an international scale, the UAE doesn't meet the international average for student achievement.	1.Some of the best STEM- related programs in the U.S. university; however, K-12 students don't perform that well in the STEM areas as compared with their peers from around the world. 2.The U.S. ranked 15th in math and 11th in science of TIMMS 2019 assessments & 25th in PISA 2018 assessments. 3.In the math and science areas, only a third of 8th grade students were at the NAEP Proficient level; however, the technology and engineering literacy assessment has promising results (46%). 4.The U.S. ranked 7th (out of 37 OECD countries) in science, 25th in math, & 5th out of 14 in computer information literacy. (Elementary and Secondary STEM Education Report in 2021)

Table 2 (continued)

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab \Emirates (UAE)	United States of America (USA)
STEM teacher education	1.STEM remains distinct and disjoint subject areas in secondary teacher education programs. No program offers an integrative STEM major and very few have integrative STEM courses. 2.Because of the lack of incentive or leadership for change, the key policy document from the Association of Canadian Deans of Education doesn't mention STEM, integration, or interdisciplinarity	1.It is compulsory for primary, lower secondary and upper secondary teachers to have a master's degree. 2.Primary school and craft teacher education is offered by faculties of education. Lower and upper secondary teachers are trained in joint programs by the faculty of science and education. School education and teacher education policy adopts Bildung-Didactics approach which enables teachers to have an autonomous role in the classroom. 3.Several in-service training projects in STEM education, such as the In-service education program in math education; The "LUMA Centre Finland" to improve the lifelong learning and research-based teaching of the teachers working; "The Innokas Network" to help teachers gain skills.	1.Teachers have to hold a Master's degree of ISCED-level 7 before they can be employed at a public school. 2.General education teacher studies contain two or three subjects and pedagogy studies. Vocational teachers take one general education subject and one vocational subject. 3.At some vocational schools, professionals with a ISCED-level 6 certificate teach practical subjects. 4.Participation in continuing education in parallel with the teaching activity is voluntary.	1.There is no STEM teacher qualification requirement stipulated nor STEM-majored pre-service training; most of the competence for implementing STEM resides in teachers' expertise. 2.The EDB offered 3 categories of in-service PDP, including (1) planning of a school-based cross-disciplinary STEM curriculum, (2) enrichment of knowledge and (3) introduction of appropriate STEM teaching and assessment strategies. 3.There are training courses organized by local universities, like "Coding Education Centre", "STEM Ed Lab", "Hour of Code".	1.The teaching profession in Ireland remains a high-status profession. 2.The National Teaching Council has defined standards and frameworks to support teacher learning within: Céim (the standards for pre-service initial teacher education), Droichead (the integrated professional induction framework), and Cosán (the framework for teachers' learning and in-service professional development). 3.Two routes to qualifying as a primary or post-primary teacher: the consecutive initial teacher education programs (an honors bachelor's degree & professional master's in education degree) or concurrent teacher education degree programs (integrating the subject specialist modules with foundational, professional, pedagogical, and school-based learning).	1.Teachers in national schools under the MOE must have obtained their teaching certification from the NIE. 2.Pre-service teachers take Bachelor of Science (Education) program, pedagogy-related courses and intern in schools to learn how math & science are taught. They have a 5-week teaching assistantship in year 2, a 5-week and a 10-week practicum in year 3 and 4, respectively. They have to complete a final-year research project. 3.Ongoing efforts raise awareness of integrated STEM learning among STEM teachers. 4.In-service teachers can participate in the annual Empowering STEM Education Professional program to build their confidence and ability.	1.An employed teacher needs to have a teacher certificate issued by the National Agency for Education. The certificate can be applied after graduating from a teacher education program. Due to teacher shortage, only 72% of full-time teachers were qualified with teaching certificates. 2.There are many ways to become qualified as a teacher, while internship in school is the commonality for each pathway. 3.Skolverket offers many in-service courses for STEM subject teachers, such as Introduction to programming in a text-based environment, Programming activities in teaching, Science and technology, Mathematics, Digital tools in science, and Sustainable development.	Three major types of STEM teacher education preparations: 1.Degree programs: (1)International doctoral program in integrative STEM education in NTNU (2)A master's degree in interdisciplinary STEM education in NTHU 2.Certificate/ diploma programs for pre- and in-service teachers. 3.Various short-term training programs (training courses, workshops) for in-service teachers. 4.Overall, the development of STEM teacher training has gradually received increasing attention; a well-constructed teacher education system for pre- & in-service STEM teachers is expected in the near future.	1.Teachers are qualified to teach their specialty area in K-12 schools after having at least either (a) a bachelor's degree in a specific field and education or (b) a bachelor's degree in a specific field and a one-year diploma in educational psychology, learning theories, and teaching methods or pedagogies. 2.Many teachers are not content experts within each of the STEM disciplines and bridging these individual fields can be a challenge. 3.Some STEM teachers' professional programs aim to equip teachers with new and effective teaching strategies, such as the TECHQUEST leadership program.	1.Most teacher education programs are subject specific (e.g., science education). 2.There is a teacher shortage. Teachers may be asked to teach in areas where they haven't been formally trained. In some states, individuals are being hired to teach without formal training in teaching.

Table 2 (continued)

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Current STEM education reforms and policy discussions	1.STEAM has found its broadest appeal in Canada in the elementary schools, extracurricular enrichment programs and within indigenous communities. 2.Canadian researchers and teacher educators have been keen to demonstrate the viability of STEM as more than four discrete disciplines, for example, ES-TEEM, STeeeEM, STEAMBED, STEHM/STEM-H, STEMMed, and STREAM. 3.The BC MoE introduced Applied Design, Skills and Technologies to resolve the challenge of clustering business, home economics, and technology in the schools. 4.Thee Council of Canadian Academies offered a thorough analysis of challenges to STEM education and a persuasive argument for equity, diversity, and inclusion.	STEM has been mainstreamed through the Finnish education system rather well, and STEM appeals to a great extent to the educators in Finland's education system; therefore, STEM educational issues are not a matter of debate in Finland.	1.The German system in general is quite static and changes need a considerable amount of time. 2.Currently, there is a national 'digitalization pact' and initiatives to enrich the teacher education and to update the school infrastructure. 3.Some states have strengthened subjects like computer science or integrated subjects like 'science and technology' in recent years.	Two endeavors on change-capacity building are focused on: 1.Integrative STEM efforts by the Education University of Hong Kong to provide teachers with a summary of literature from foreign countries to formulate a theoretical basis in STEM implementation and a set of guidelines in undertaking the planning and offering of integrative STEM education. 2.The "CEATE Awardee Workshop" aims to gather and formulate a professional knowledge base in teaching DT and STEM and to share knowledge with local and global TE and STEM communities through paper presentations.	1.The Department of Education's STEM Education Policy Statement recognizes the need to promote and diversify participation and increase success in STEM with 4 pillars: 1. Nurture learner engagement and participation; 2. Enhance early years practitioner and teacher capacity; 3. Support STEM education practice; 4. Use evidence to support STEM education. 2.The Department of Education and Skills has also developed guidelines to support STEM education partnerships which has led to many STEM education initiatives and partnerships being formed to support STEM learning and activities.	1.In 2019, SG revealed the revised science curriculum framework that had Science for Life and Society as the goal for science education in Singapore. 2.There are currently discussions around how integrated STEM education can be introduced into schools to augment science and mathematics teaching.	1.Changes for STEM education between the 2011 and 2018 curriculum indicate a clear direction of how STEM education is being reformed. 2.The biggest changes were in Math and Technology subjects that related to the introduction of programming (predominantly in Math and also seen in Technology) and safety regarding the use of technology to the compulsory curriculum. 3.A change that related to the acknowledgement of the relevance of digital tools in core content was also seen in all STEM subjects.	1.Holding activities to cultivate female STEM talents. 2.Developing training courses to assist STEM teachers who commit to implementing STEM education. 3.Providing various STEM-related activities for students to explore their interests and enhance willingness to pursue STEM careers. 4.Applying multiple digital devices to help STEM courses delivery.	1.The Education Vision 2020 aims to improve the educational system of K-12 and prepare students for STEM challenges in colleges and future professions by introducing a STEM curriculum in K-12. 2.The UAE Vision 2021 aims to render the UAE one of the world's best countries and to bring this vision into action and increase student achievement in foreign testing. 3.The Innovation Hub, which was launched by Al Bayt Mitwahid Association in collaboration with Google, has given a great deal of media coverage to STEM education in the UAE.	1."Charting a Course for Success: America's Strategy for STEM Education" was released by The White House (2018) that set out a federal strategy for a future where all Americans will have lifelong access to high-quality STEM education. 2.The "Standards for Technological and Engineering Literacy" was released by ITEEA in 2020. 3.Battelle for Kids' (2019) "P21's Frameworks for 21st Century Learning" defined and illustrated the skills & knowledge students need to succeed in work and life. 4.The U.S. organizations published a joint document "STEM4: The power of Collaboration for Change" that identified 3 main principles to drive and implement STEM education research and practices.

A Comparison of Trends and Issues in STEM Education

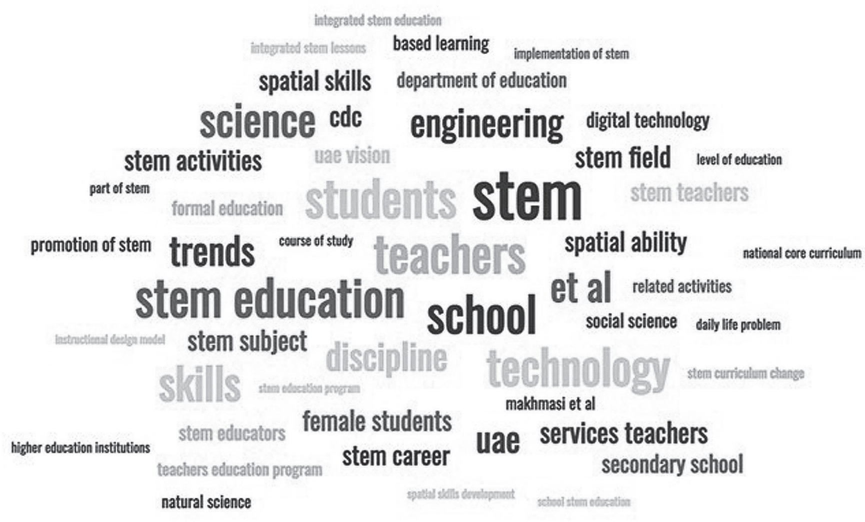
In this section, major trends and issues in STEM education among the 10 countries are discussed and compared in terms of the beforementioned aspects such as contexts and status of STEM education. In this book, “trend□is defined as “a general direction in which something is developing or changing” and “issue” is referred to as “an important topic or problem for debate or discussion.” Table 3 shows a summary of the STEM trends and issues in the 10 highly competitive countries.

Comparison Component 10: Trends in STEM Education

For the trends in STEM education among the 10 countries, some directions are similar, while others are specific for individual countries. Eight prevalent trends are observed as follows. First, increasing the momentum and support of STEM teachers’ preparation and professional development through various channels of capacity building (e.g., HK, SG, SE, TW, the USA). Second, strengthening networks or partners from outside of schools to diversify students’ STEM learning experiences in non-formal education (CN, FI, DE, IE, TW). Third, increasing the importance of STEM education through introducing STEM curricula in formal education, making STEM-related national policies and reforms, incorporating STEM policy into school assessment, or continuing national investment in STEM research (HK, FI, SG, SE, the UAE, the USA). Fourth, accelerating efforts to increase the number of women in the STEM field (DE, SG, TW). Fifth, applying digital devices, eLearning video services, or social media in STEM teaching and learning (DE, TW, the USA). Sixth, enhancing the provision of inclusive and integrated STEM environments such as applying the phenomenon-based approach/ project-based learning/ authentic hands-on problem solving, emphasizing holistic or transversal competency development, or proposing a well-structured STEM instructional design model (FI, HK, IE, TW, the UAE). Seventh, increasing emphases on technology subjects such as programming and computer technology in formal curricula (CN, SE). Eighth, emphasizing science and engineering career developments or aspirations in schools (FI, the UAE).

In addition, a word cloud of the STEM trends was generated that provides a visual representation of the above STEM trends (see Figure 1). In the figure, the larger and bolder the term, the more frequently it appears in the content of STEM trends in the 10 country reports. The word cloud indicates that STEM education, students, teachers, STEM field, and STEM subject are the five most relevant words in these texts. The results are closer to the above paragraph where we find that most countries recognize the importance that educators play in STEM education. In addition, students' STEM learning experience in school or out-of-school is highlighted; and technology is treated as an integral part of STEM education.

Figure 1 A word cloud of STEM trends in the 10 countries



Comparison Component 11: Issues in STEM Education

Most countries have recognized the importance of STEM talents and workforce and have made great efforts to promote STEM education through various forms of access. However, they face a number of problems and important topics for debate or discussion. Below are six issues commonly raised by these countries.

First, the traditional concept of separate S.T.E.M. is dominating in schools, in which discipline-based curricula and teaching is popular (CN, FI, DE, SG, TW, UAE, the USA). Under such a framework of discrete subjects, schools might offer activities and units that challenge students to integrate the four STEM subjects, while integrative STEM courses are rare, especially in secondary schools or higher levels of education.

Second, since tradition education prefers isolated STEM subjects, integrative STEM education/ curricula are not accessible, flexible, or sufficient, especially in formal education (CN, FI, IE, SG, SE TW, the USA). For example, curriculum materials in schools are mostly designed for disciplinary-oriented teaching rather than the integrated STEM approach. The lack of dedicated time for STEM education is a prevalent issue, as well as the insufficiency of interdisciplinary collaboration among teachers. Besides the lack of an integrated STEM curriculum, it is often observed that technology and engineering education have been overlooked. These subjects are not often offered in all schools throughout these countries and their accessibility could be further reduced through the learners' subject choices, especially when they move to higher levels of education where there are more diverse and academic-oriented elective courses. Besides, new technologies such as AI and related materials need further efforts to develop and deliver to increase students' technology competency.

The third issue is related to STEM teacher education and professional development. In most countries, the teacher education traditionally emphasizes discipline-oriented teaching; that is, most teacher education programs still focus on preparing teachers in a specific STEM discipline (e.g., science education or math education). Therefore, teachers usually lack integrated STEM competence and teaching approaches, particularly at the secondary or higher education levels (CN, FI, DE, IE, SG, SE, TW, the USA). Some countries not only face the problem of low teachers' readiness to embrace integrated STEM, but also suffer from a deficit in the number of qualified STEM teachers and lack of teacher preparation to teach technology in K-12 schools. To overcome these problems, some countries are making vigorous efforts to establish a systematic STEM teacher education program, to provide diverse and accessible in-service training for professional development, or to encourage research on developing a variety of STEM interdisciplinary modules in order to search for the best practices for developing and delivering STEM education.

Fourth, students' low interest in STEM careers and ambiguous job preferences in STEM fields were identified as one major issue that might lead to the lag in preparing a highly talented STEM workforce (e.g., SG, the UAE, the USA). STEM in most countries is not an examinable subject, so even though STEM lessons are oftentimes applied and hands-on based and are considered enjoyable, such enjoyment may not easily translate into pursuit of STEM higher degrees or careers. Inspiring students to pursue a career in STEM requires more teachers to have some understanding of the STEM careers available, and to be actively involved in introducing STEM careers to students, especially at an early age.

Besides, gender stereotyping or underrepresentation of females in STEM fields is another concern that has drawn a great deal of attention (e.g., IE, SE, TW, the UAE, the USA). For example, representation is an important issue to be addressed in Irish STEM education as set out through the STEM education policy nationwide. Since a high differential in female and male participation in the technology-based subjects is observed, a focus has been placed in schools from early years to higher education to increase female representation.

Sixth, the lack of a clear understanding of STEM or the lack of explicit goals and policy for STEM education in K-12 schools is another issue (e.g., HK, SG, TW, USA). The concept of STEM education in some countries has not reached a consensus among the academic bodies, professional associations, and policy making communities. The term oftentimes encompasses both the singular and integrated disciplines, and the distinction is not clear. For example, STEM in SG has been used to refer to the mono-disciplines and integrated disciplines interchangeably, so teachers are often confused about how it differs from what they are currently teaching as STEM subjects in schools. As for the issue about the lack of STEM education, it differs by country. In the USA, the goals to improve students' achievement in science and mathematics to cultivate STEM-related professionals are clear. On the contrary, lacking explicit goals and policy for STEM education in Taiwan is a problem, indicating that there is a gap between policy-making and practice. More open and rigorous discussions among stakeholders are needed to make a systematic STEM policy and goals to clearly guide the implementation of STEM education at all levels of education.

To sum up, STEM education is drawing great attention in the 10 countries, and some of them even consider it as a priority in current education reform. Despite the fact that the traditional education with a focus on mono-disciplinary approach is dominating, a growing number of educators are aware of the importance of applying an interdisciplinary approach to encourage students to understand themes and ideas that cut across disciplines, to connect them between different disciplines, and to extend their relationship to the real world for better redefining problems outside of normal boundaries and generating solutions based on a new understanding of the complex situations. Assuredly, STEM education will continue to be promoted in these countries and will move forward in a rapid manner as concerted efforts are made by policy makers, teachers, and the other stakeholders.

Table 3 A summary of trends and issues in STEM education for the 10 countries

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
Major trends in STEM education	1.Indigenous ways of knowing and learning have been taken up 2.EDI in STEM education has been advocated 3.Expanding the STEM cluster, like STEAM, STEAMD (design), STEM-H (health), etc. 4.Alternatives to STEM (STS & STSE) have been considered 5.Resolving the neglect of T&E in STEM	1.Implementing a national core curriculum emphasizing STEM competences 2.Applying the phenomenon-based approach to education, including STEM education 3.Emphasizing learning of transversal competencies as a part of STEM education 4.Emphasizing science and engineering careers in middle school curricula 5.Strengthening networks to support STEM Education	1.STEM education is involving partners from outside of schools 2.Promotion of women in STEM education is a key 3.Digitization is increasingly included in STEM education 4.Clustering and arranging of individual offers for school education 5.Vocational education makes a major contribution to STEM education	1.Official P\ positioning of STEM: more a curriculum renewal than a formal discipline of learning 2.Authentic hands-on problem solving as a core learning experience in STEM 3.Diversifying implementations for promoting STEM education by schools 4.The evolving popularity of iconic items in STEM promotion 5.Variation in channels of capacity building for STEM curriculum change	1.Emphasizing holistic competency development 2.Increasing representation in STEM 3.Enhancing provision of inclusive and integrated STEM environments 4.Promoting connected STEM learning experiences 5.Increasing awareness of pedagogies to compliment STEM learning 6.Incorporating STEM policy into school assessment to achieve targets	1.Reforming STEM through STEM education review 2.Increasing the momentum for STEM education professional development 3.Meeting the increasing demand for STEM-related jobs 4.Creating a culture to support lifelong learning and a versatile workforce 5.Accelerating efforts to increase the number of women in STEM 6.Increasing research into STEM education	1.Increased emphasis on STEM in formal education 2.Increased responsivity to technology in society 3.Increase in STEM-related activities for students and preparation for teachers 4.Female students continue to outperform male students in compulsory school STEM education 5.Continued national investment and prioritization of research in STEM	1.Cultivation of female talents in STEM fields 2.Organizations and institutions help with developing STEM teacher training 3.Great attention on STEM learning outside schools 4.Proposal of a well-structured STEM instructional design model 5.Development of a context-based assessment system in STEM education 6.Applying digital devices in STEM education	1.The increased demand for STEM in education has been implemented through national policy and reform 2.Project-based learning has been adopted as the main STEM instructional strategy 3.The curriculum integration has been pursued 4.STEM career aspirations have been explored 5.Culturally-embedded resources have been provided	1.STEM educators will use more eLearning video services even after the pandemic is over. 2.STEM educators will incorporate social media into their classrooms 3.STEM educators will use more artificial intelligence (AI) in the classroom 4.Increase the importance of STEM education 5.Increased teacher training in STEM education

Table 3 (continued)

Comparison Components	Countries									
	Canada (CN)	Finland (FI)	Germany (DE)	Hong Kong SAR (HK)	Ireland (IE)	Singapore (SG)	Sweden (SE)	Taiwan (TW)	United Arab Emirates (UAE)	United States of America (USA)
Major issues in STEM education	1.Isolated STEM subjects in schools and rarely integrative STEM courses 2.STEM education is not easily accessible or accommodated 3.MST pre-exists as core to STEM; rethinking MST configurations is challenging 4.Too many alternatives to STEM, like MST, STS, etc. 5.Full membership in clusters is not easy; T&E are neglected	1.The teacher education tradition emphasizes discipline-oriented teaching 2.Discipline-based curricula emphasize teaching of STEM subjects as separate subjects 3.Curriculum materials emphasize disciplinary-oriented teaching 4.Interdisciplinary collaboration among teachers is insufficient 5.Second and third cycles of education emphasize disciplinary orientation	1.The government lacks control of the teaching activities 2.The STEM education is determined by local available partners 3.The concept of separated S.T.E.M. is dominating in German schools 4.The regular education system lacks technology education 5.Germany's teachers lack integrated STEM-competence 6.The infrastructure of Germany's schools is inadequate	1.Positioning and the clarity of the vision and actions of STEM curriculum change 2.The challenging status of learning in practical problem-solving with tangible outcomes 3.Implication of the "partial curriculum" status of the STEM implementation 4.Effect of iconic item on the purpose and course of the STEM implementation 5.The challenged effectiveness of supports and enrichments from PDPs 6."What will STEM be in the near future?": A cautionary probing into the momentum of STEM Promotion in schools	1.Accessibility and achievement for STEM learners need to increase 2.The critical role of STEM teachers has not drawn enough attention 3.Lack of an integrated STEM approach 4.A lack of flexibility in STEM subject offerings 5.Gender stereotyping, curriculum accessibility, and resourcing of STEM education are three major challenges in STEM culture	1.Lack of a clear understanding of STEM 2.Insufficient protected time for STEM 3.Low levels of teacher readiness to embrace integrated STEM learning 4.Low interest in STEM careers 5.Conflicting assessment demands for STEM learning 6.Rigid traditional structures of STEM in higher education	1.There is a deficit in the number of qualified teachers 2.Females are underrepresented in STEM fields at upper secondary and higher education levels 3.Lack of dedicated time for STEM education subjects 4.Ambiguity in the Technology subject 5.Lack of teacher preparedness to teach Technology	1.Lack of explicit STEM education goals and policy in K-12 education 2.Lack of systematic STEM teacher education program in higher education 3.Teachers' challenge of adopting hands-on activities in online STEM education 4.Lack of varied STEM interdisciplinary modules 5.Diversity issues in classrooms	1.Lagging in preparing highly talented STEM workers in the past 2.Traditional learning strategies are not suitable for preparing a STEM workforce 3.Isolated (S, T, E, and M) concept of STEM education 4.Students' ambiguous job preferences in STEM fields 5.New technologies such as AI and related materials are still in the developing stage in schools	1.The need for STEM education is questioned. 2.The best practices for developing and delivering STEM education are still being searched for. 3.Improving student achievement in STEM requires a major reform. 4.Inspiring students to pursue a career in STEM requires more teachers' active involvement. 5.Most teacher education programs are still focused on preparing teachers in a specific STEM discipline. 6.Lack of qualified STEM teachers.

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