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A Comparison of STEM Education Status and Trends in Five Highly Competitive Countries in the Asia-Pacific Region

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ABSTRACT

Aiming to identify the status and trends in the STEM education in the Asia-Pacific (APAC) region, this paper summarizes the findings of STEM education from the following five highly competitive APAC countries—Canada (CA), Hong Kong SAR (HK), Singapore (SG), Taiwan (TW), and the United States of America (USA). After that, a cross-country comparison is made concerning three aspects (background, current status, trends and issues) and 11 components of STEM education. Consequently, 11 conclusions, corresponding to the comparison components, are generated. To sum up, STEM education is drawing great attention in the five APAC 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 of 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. In addition, VET may play a vital role as a natural delivery system for STEM education.

Keywords: STEM education, comparative analysis, highly competitive countries, Asia-Pacific (APAC) Region

BACKGROUND AND PURPOSE

STEM education is a field of study that combines science (S), technology (T), engineering (E), and mathematics (M). The quantity and quality of talented individuals in STEM fields contribute to a nation's overall competitiveness. Taiwan and many countries around the world are vigorously promoting the training of STEM professionals and the enhancement of STEM literacy for all as one of the key education objectives.

Aiming to achieve the following two goals, the first two authors edited a non-profit book (Lee & Lee, 2022; hereafter called the STEM book) which was published in late 2022: (1) to strengthen mutual understanding and connections between Taiwan and other highly competitive countries in the area of STEM education; and (2) to give highly competitive countries the opportunity to share their experiences in STEM education, mainly at the primary and secondary levels. The two editors-in-chief formulated manuscript guidelines including cross-country comparison components. Then, they invited STEM educators from 10 countries in the top 15 countries/economies in the International Institute for Management Development (IMD) World Competitiveness Ranking 2021 to follow the guidelines to write up country-report chapters. A peer review of all manuscripts was conducted and authors were requested to make necessary revisions. After that, the three authors of this paper made a cross-country comparison which was presented as the 11th chapter. That is to say, the STEM book comprises 10 country reports and one cross-country comparison.

All vocational education and training (VET) programs address not only technology but also some aspects of science, mathematics, and engineering. That is, all occupationally oriented VET is STEM-related, and VET is a natural delivery system for STEM education (NASDCTEc, 2013; Stone, n.d.). However, what are the STEM education status and trends in the Asia-Pacific (APAC) region? To answer this question, a country-specific study and cross-country comparison should be conducted.

Timely analysis and understanding of the status and trends in STEM education can help both STEM and VET stakeholders realize and cope with them. Educating and training in the direction of the trend and resolving the important issues can help maximize the chances of success in STEM and VET. Therefore, the purpose of this paper was to identify the status and trends in the STEM education in the five APAC countries. The five highly competitive countries were all APAC countries/economies in the 10 countries reported on in the STEM book. They were Canada (CA), Hong Kong SAR (HK), Singapore (SG), Taiwan (TW), and the United States of America (USA). STEM education in this paper 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.

METHOD AND PROCEDURE

To achieve the above purpose, a cross-country analysis with a word cloud analysis was employed. Aiming to realize differences and similarities with respect to the components analyzed, a cross country analysis is a comparison of some specific components of analysis across countries (IGI Global, 2021). The following four steps proposed in Bereday's comparative method in education were used in the cross country analysis: (1) description of STEM education materials in each country, (2) interpretation of the STEM education data in the matrix of sociological circumstances in which they operated; (3) juxtaposition in which STEM education materials from different countries were tabulated side by side to see whether they can be compared, and (4) comparison of the STEM education conditions which were later redefined by the authors as a balanced (i.e., evenly matched) and simultaneous alignment (i.e., cross referenced) (Bereday, 1977). A word cloud is a visual representation of word frequency. Aiming to identify the focus of written material, a word cloud analysis is a simple method not only to analyze the content of the text, but also to display the higher frequency words in the text in a larger font (Atenstaed, 2012).

The data analyzed in this paper were extracted from the STEM book and processed as follows:

1. Five country-specific STEM education status and trends

For the STEM book, every book chapter author(s) was/were requested to keep the length of each chapter between 10,000 and 12,000 words, and to state their STEM education status and trends based on the three aspects and 11 components shown in Table 1. For this paper, each country's STEM education status and trends were extracted from the five country report chapters. The five country-specific trends files were combined into one file and imported into the online word cloud generator, WordItOut, to generate one word cloud, shown as Figure 1. When examining the word cloud, common English words were ignored. The word cloud was applied to confirm and make up the data described below.

Table 1: The three aspects and 11 components summarized and compared in this paper

Aspects	Components
1. STEM education background	1.1 Supply and demand of a STEM-skilled workforce
	1.2 Schooling System
	1.3 Influence of Government on STEM Education
2. Status of STEM education	2.1 Contexts of STEM education
	2.2 STEM education system/framework
	2.3 STEM-related activities in non-formal education
	2.4 STEM learning assessment and career development
	2.5 STEM teacher qualification and professional training
	2.6 Current STEM education reforms and policy discussions
3. Trends and issues in STEM education	3.1 Major trends in STEM education
	3.2 Major issues in STEM education

2. A cross-country comparison of STEM TVE trends and issues

As stated earlier, a cross-country comparison of STEM education was presented in the 11th chapter of the STEM book. The three comparison aspects and 11 comparison components, shown in Table 1 were prescribed in the manuscript guidelines and sent to authors when they were invited to make contributions to the STEM book. After the peer review process and necessary revisions of all manuscripts were completed, the findings regarding the comparison components were drawn from the manuscript and listed in comparative tables (i.e., Tables 1, 2 and 3), to request its author's/authors' confirmation. In this paper, the comparison of STEM status and trends was extracted from the 11th chapter of the STEM book. The extracted data were reexamined with the word cloud, and necessary supplements as well as rephrasing were made.

RESULTS AND DISCUSSION

Based on the three aspects and 11 components shown in Table 1, the results of this paper are presented and discussed as follows:

1.A comparison of the STEM education background

This section compares the STEM education background of the five 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 five countries. Table 1 shows a summary of the three comparison components for each country.

1.1 Supply and Demand of STEM-Skilled Workforce

According to the country's reports, all five APAC 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 mentioned that the gap between supply and demand of the STEM workforce is massive. The STEM-related job vacancies have been increasing greatly, while the number of STEM graduates cannot keep pace with the skill demand. Faced with 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.

1.2 Schooling System

For the structure of the schooling system in the five SAPAC countries, some countries with a federal system of government (such as CA 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 HK, 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). In addition, the education systems in countries such as SG and TW have a dual-track feature in which there are separate high schools and colleges/universities dedicated to TVE.

1.3 Influence of Government on STEM Education

The five 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 HK, TW, and the USA, 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 HK and TW) has developed national guidelines to promote the STEM education curriculum and partnerships between schools, teachers, and industries. The Canadian government, by contrast, allocates most of the federal funding to postsecondary education and research, while funding for K-12 STEM education is negligible.

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

Comparison Components	Countries				
	Canada (CA)	Hong Kong SAR (HK)	Singapore (SG)	Taiwan (TW)	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. 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. 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 either males or females.	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. 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 do not have a bachelor's degree and work primarily in health care, construction trades, installation, maintenance and repair, and production occupations.

Schooling system	1.Decentralized system of education, wherein curriculum and policy are under the jurisdiction of each province and territory. 2. K-12+ STEM education in CA includes elementary, secondary, and tertiary or postsecondary education levels.	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. 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.	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. 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.

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 HKSAR Government plays a dominant role in developing STEM education in schools through enacting policy and appropriating funding, resources and support. 2. STEM is considered as a measure to equip future generations for the keen global competition ahead in HK. 3. The HK government promotes and starts STEM early in primary and secondary schools to narrow the talent gap.	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 latest nationwide 12-year basic education curriculum guidelines treat STEM as 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. 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.

Source: Extracted from Lee et al., 2022.

3.A comparison of the status of STEM education

This section presents a comparison of the current STEM education in K-12 schools for the five APAC 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 qualifications and professional training, and current STEM education reform and policy discussions. Table 2 shows the summarized information of each country for the six above-mentioned components.

2.1 Contexts of STEM education

The current STEM practices in schools, key statistics, and highlights of policies and strategies in the five APAC 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 to secondary school. By contrast, the subjects of technology and engineering are not so prevalent, and fewer efforts have been concentrated on them. Some countries, such as SG, are examples of the separated STEM education approach. Even though monodisciplinary teaching is still popular in most countries, the interdisciplinary or transdisciplinary approach is highly promoted. As for the proportion of students in STEM fields, some countries, such as SG and TW, have more than one-third of students in STEM postsecondary education. 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 HK, 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. On the other hand, Canadian federal policies and funding have little effect on K-12 STEM education.

2.2 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 HK and the USA) have set up clear goals for STEM education in formal documents. For example, in the USA, there are three broad goals for STEM education—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' interest and solid knowledge in STEM, to strengthen their 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, 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. 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.

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 five APAC 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 SG and 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.

2.3 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 school 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.

2.4 STEM learning assessment and career development

Students' STEM learning performance in the five APAC 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 HK, SG, and TW). As for the gender difference, boys tend to have higher scores in mathematics and science measures than girls. In the USA, although K-12 students do not perform that well as compared with their 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, 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, 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 TW), students in STEM programs usually have internship or apprenticeship opportunities to prepare them for a specific type of job, in order to meet the STEM-related industry's need for highly skilled employees.

2.5 STEM teacher qualifications 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 CA and HK 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 experience. At the other extreme, STEM teachers are well trained in an intradisciplinary or transdisciplinary manner. For example, Taiwan provides three types of integrative/interdisciplinary STEM teacher education preparation or in-service training: master's and doctoral degree programs, 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 five APAC countries.

2.6 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. In countries such as SG and TW, recent curriculum reform has taken STEM education into consideration. Taking TW as an example, more opportunities to implement integrative STEM education are provided in the school-based curriculum in the last curriculum reform.

Table 2: A summary of the status of STEM education

Comparison Components	Countries				
	Canada (CA)	Hong Kong SAR (HK)	Singapore (SG)	Taiwan (TW)	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 have 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. Policy documents announce the positioning of STEM education in HK indicating that 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 primary and secondary schools have implemented STEM education.	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 it is 47% for university.	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. There is 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.

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, it has been ineffective in providing alternatives to comprehensive high schools for STEM immersion.	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 through 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. 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 secondary 3 & 4, different science subjects are offered for selection, and elementary math is required. The Applied Learning Programme (ALP) is available in all secondary schools; it 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 technological and economic development. Universities have programs to develop top talents in S.T.E.M.	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 of 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 the Mushroom experiment, Incubators design, Mousetrap car, Bridge design, Seismic structure design, etc.	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.

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 the "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 Gearing Up program immerses children, youth, and teachers in summer STEM camps to investigate engineering, science, and technology in a fun, safe, & educational environment.	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 make up over 80% of the total number, and most activities are related to the science subject. 3. The faculties of science and engineering of local universities organize 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.	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. 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 with non-formal access.	Most states recognize the importance of STEM and have developed websites providing resources or have set up centers to support STEM education via offering grants, events, activities, competitions, etc. (such as the STEM Action Center in Utah).

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. There are no measures of performance in engineering and technology education.	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 level, students have many paths for STEM career development, such as opting for STEM-related elective subjects, taking a career oriented "Applied Learning course," and choosing STEM-related undergrad courses in university. However, the actual figures of students taking them needs further observation. 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. Assessment is through students' results from school-based tests, examinations, and 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 the OECD average is 7%. 3. To pursue a STEM course at tertiary level, students must meet minimum grade requirements at the secondary school and junior college levels.	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) 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. Some of the best STEM-related programs are in U.S. universities; however, K-12 students do not 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 in 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)

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 does not mention STEM, integration, or interdisciplinarity	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 offers 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. Teachers in national schools under the MOE must have obtained their teaching certification from the NIE. 2. Pre-service teachers take the 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 years 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.	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. 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 have not been formally trained. In some states, individuals are being hired to teach without formal training in teaching.
Current STEM education reforms and policy discussions	1. STEAM has found its broadest appeal in Canada in 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, ESTEEM, STeeeEM, STEAMBED, STEHM/STEM-H, STEMMed, and STREAM.	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	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. 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 their willingness to pursue STEM careers. 4. Applying multiple digital devices to help STEM courses delivery.	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. practices.

	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. The Council of Canadian Academies offered a thorough analysis of challenges to STEM education and a persuasive argument for equity, diversity, and inclusion.	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.			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

Source: Extracted from Lee et al., 2022.

4. A comparison of trends and issues in STEM education

In this section, major trends and issues in STEM education among the five APAC countries are discussed and compared in terms of the aforementioned aspects such as contexts and status of STEM education. In this paper, "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.

3.1 Trends in STEM education

For the trends in STEM education among the five APAC countries, some directions are similar, while others are specific for individual countries. Seven 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, TW, and the USA). Second, strengthening networks or partners from outside of schools to diversify students' STEM learning experiences in non-formal education (CA and 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, SG, and the USA). Fourth, accelerating efforts to increase the number of women in the STEM field (SG and TW). Fifth, applying digital devices, eLearning video services, or social media in STEM teaching and learning (TW and 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 (HK and TW). Seventh, increasing emphases on technology subjects such as programming and computer technology in formal curricula (CA).

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 five APAC country reports. The word cloud indicates that STEM education, learning, teachers, students, and technology are the five most relevant words in these texts. The results are closer to the above paragraph where the authors 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.

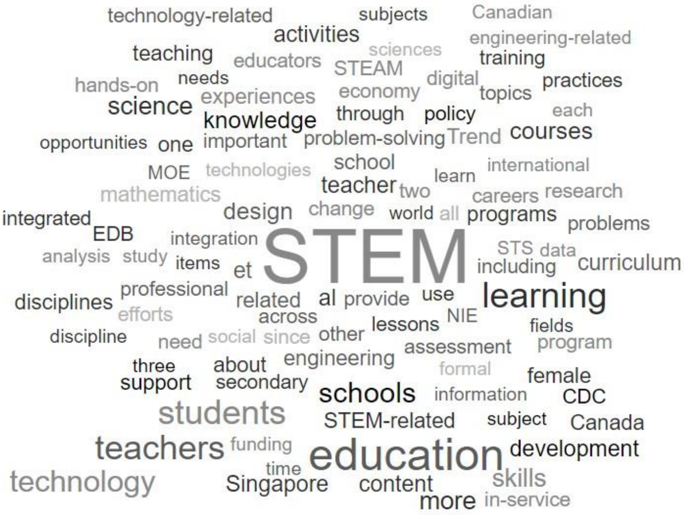

Figure 1: A word cloud of STEM trends in the five APAC countries

3.2 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 five APAC countries.

First, the traditional concept of separate S.T.E.M. is dominating in schools, in which discipline-based curricula and teaching is popular (CA, SG, TW, and 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 traditional education prefers isolated STEM subjects, integrative STEM education/curricula are not accessible, flexible, or sufficient, especially in formal education (CA, SG, TW, and the USA). For example, curriculum materials in schools are mostly designed for disciplinary-oriented teaching rather than for 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 (CA, SG, TW, and the USA). Some countries not only face the problem of low teacher 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 a lag in preparing a highly talented STEM workforce (e.g., SG and 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.

Fifth, gender stereotyping or underrepresentation of females in STEM fields is another concern that has drawn a great deal of attention (e.g., TW and the USA). 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, and the 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 of 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, the lack of explicit goals and policy for STEM education in Taiwan is a problem, indicating that there is a gap between policy-making and school 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.

Table 3: A summary of trends and issues in STEM education

Comparison Components	Countries				
	Canada (CA)	Hong Kong SAR (HK)	Singapore (SG)	Taiwan (TW)	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. Official 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. 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.Cultivation of female talents in STEM fields 2.Organizations and institutions help with developing STEM teacher training 3.Great attention to 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. 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

Major issues in STEM education	1. Isolated STEM subjects in schools and few integrative STEM courses 2. STEM education is not easily accessible or accommodated 3. MST pre-exists as the core of 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. Positioning and 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. Iconic objects as obscurers of the purpose and course of 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. 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.Lack of explicit STEM education goals and policy in K-12 education 2.Lack of systematic STEM teacher education programs 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. 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.

Source: Extracted from Lee et al., 2022.

CONCLUSIONS

Based on the above results and discussions, 11 conclusions, corresponding to the comparison components, are drawn 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 five 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 to upper secondary school. 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 transdisciplinary 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.

To sum up, STEM education is drawing great attention in the five APAC 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 of 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. In addition, VET may play a vital role as a natural delivery system for STEM education.

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