Status and Trends of STEM Education in Highly Competitive Countries: Country Reports and International Comparison

Technological and Vocational Education Research Center (TVERC),
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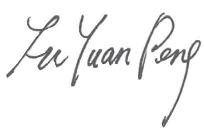
CONTENTS

PREFACE

The four core STEM fields, science (S), technology (T), engineering, (E) and mathematics (M) commonly place emphasis on problem solving, critical thinking, and innovation skills. Therefore, 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. All countries can learn from each other in regards to the policies and practices of promoting STEM education, and problems encountered during the process can also be quickly tackled through international exchanges and cooperation.

Globally speaking, Taiwan has a high level of national competitiveness. The World Competitiveness Center of the International Institute for Management Development (IMD) in Switzerland annually ranks countries and economies on competitiveness based on four major criteria and hundreds of sub-criteria. Taiwan ranked 8th in 2021 and 7th in 2022 in the IMD World Competitiveness Ranking, its two best showings since 2013.

In order to strengthen mutual understanding and connections between Taiwan and highly competitive countries in the area of STEM education, and to give highly competitive countries the opportunity to share their experiences in STEM education, the K-12 Education Administration of the Ministry of Education subsidized the publication of the book *Status and Trends of STEM Education in Highly Competitive Countries: Country Reports and International Comparison* by the Technological and Vocational Education Research Center of National Taiwan Normal University. Ten STEM educators in the top 15 countries and economies in the IMD World Competitiveness Ranking 2021—Overall category were invited to each write a chapter on country-specific STEM education statuses and trends. The two editors-in-chief of the book and a doctoral candidate then made a cross-country comparison, which is presented in the 11th chapter. I am grateful to all the experts involved in the book's production, and I hope that this book can contribute to improving STEM education, benefiting students, and promoting international exchanges.



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Status and Trends of STEM Education in Canada

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Abstract

Canada is at various crossroads and one of these is STEM education. The Canadian government anticipates that STEM will be a catalyst for economic and cultural change. After a decade of federal policies and funds for STEM education, there is little to show in K-12 schools and teacher education programs. The vast majority of non-profit, private sector, and professional society policy recommendations reinforce the federal government's lead. This chapter provides a critical analysis of challenges, policies, practices, and trends in STEM education in Canada. The chapter primarily focuses on K-12 STEM education and teacher education and tangentially on postsecondary STEM education. The analysis is presented in three sections: 1) context of STEM education in Canada with a focus on economic and educational policies and funding trends; 2) trends in frameworks and systems of K-12 STEM education and STEM teacher education; and 3) oversights of engineering and technology in STEM education practice and policy across Canada. For instance, five provinces and two territories do not have technology course requirements for graduation from high school. None of the provinces and territories have an engineering requirement. Integrative STEM education, a potential catalyst recommended by a range of researchers and teachers across the world, has also not had much influence on K-12 schools and teacher education in Canada. Perhaps Indigenous ways of holistic learning and integrative STEM will influence necessary changes. Iterations on STEM, such as STEAM, STEEM, and STEM-H provide additional challenges across the educational system in Canada. There is a profound sense that STEM education has to change but there are also longstanding disagreements over the how, what, and why of necessary changes. Through critical analysis, this chapter provides insights into key issues and trends in STEM education in Canada to facilitate potential changes.

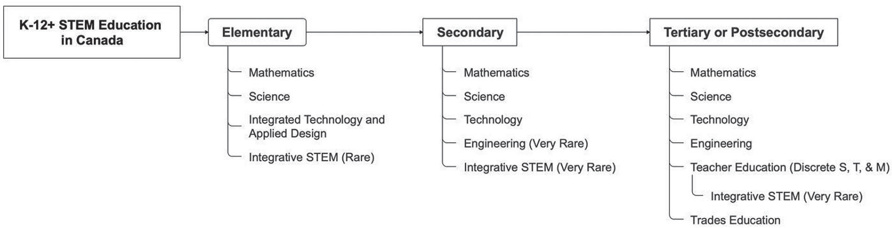
Keywords: STEM education, integration, Canadian culture and education, BIPOC students, engineering and technology

Introduction

Given the "STEM in Education" partnership with Australia and China, it would appear that Canada is quite advanced and coordinated. Bi-annual Pacific Rim conferences held alternatively at Beijing Normal University, Queensland University of Technology, and the University of British Columbia (UBC) have been popular and successful (e.g., Anderson et al., 2021). Yet beneath the surface, STEM education in Canada is disjointed at best. This is partially due to the decentralized system of education across Canada, wherein curriculum and policy are under jurisdiction of each province and territory. Although each Ministry of Education (MoE) in the 13 provinces and territories indicates the importance, none have translated this into an integrative STEM education curriculum. Similarly, at the federal level, Prime Minister Trudeau (2018) announced that the government is "investing massively in STEM education, including getting more women and girls into STEM education." Yet these funds have not been "massive" and have not translated into STEM programs in the schools. This disconnect is also partially due to the traditions in schools and teacher education programs that isolate science, technology, engineering, and mathematics education into separate courses and programs. Whether Canada is more or less advanced than other countries in STEM education is a task of comparative analysis.

STEM education in Canada is based on a conventional framework of discrete or isolated disciplines of science, technology, engineering, and mathematics. Integrative STEM education is slowly showing signs of adoption in elementary schools but is rare across secondary and teacher education programs (Figure 1). At postsecondary levels, about half of all those studying within a STEM discipline are international and immigrant students. Summarizing its key educational initiatives, the Government of Canada (2021a) reasoned that "as more and more businesses and organizations look to innovate, modernize and grow, the demand for people who can fill STEM-related jobs will only increase." In terms of supply and demand, there are current shortages of engineers, IT workers, healthcare specialists, and some tradespeople, especially electricians (RBC, 2021; Shortt et al., 2020).

Figure 1 STEM education in Canada



This chapter provides a critical analysis of challenges, policies, practices, and trends in STEM education in Canada. The chapter primarily focuses on K-12 STEM education and STEM teacher education, and secondarily on postsecondary STEM education. The first section addresses the context of STEM education in Canada with a focus on economic and educational policies and funding trends. Federal government policies and funding primarily address postsecondary STEM education. About 25% of all postsecondary students are STEM majors, and government policies aim to increase this for economic purposes (Johnson et al., 2020; Statistics Canada, 2021). These policies have had little effect on K-12 practices and teacher education programs. The second section addresses trends in frameworks and systems of K-12 STEM education and STEM teacher education. Complex integration of the four discrete disciplines in STEM (I-STEM) is commonly found in elementary schools but rarely in secondary schools and teacher education programs in Canada. Federal policies for teacher education overlook STEM and the importance of complex integration. At the same time, regression to the discrete disciplines of STEM has deprioritized or helped eliminate science, technology, and society (STS) as a viable reform in Canadian education. The third section explores oversights of engineering and technology in STEM education practice and policy across Canada. This section documents historical problems in the marginalization of the content and discipline of technology. For STEM education to be a successful innovation or reform in Canadian education, these oversights have to be redressed. The chapter concludes with a summary.

Status of STEM Education

Given economic indicators, one might suggest that it makes sense to treat STEM education as just another cluster of subjects. About 40% of Canada's exports are extracted resources and related products (minerals, oil and gas, and wood) while only about 20% are manufactured goods, including pharmaceutical products. Services, including real estate, account for about 60% of the value of the country's Gross Domestic Product (GDP) while only about 15% is construction and manufacturing. Provincially, Alberta's primary export is oil and gas (61%) while British Columbia's is forest products (31%) and minerals (24%). Raw lumber or forest products account for 4.5% of the country's exports but finished furniture is only about 1.1%. By comparison, Canada's high-tech sector is also small at just 7% of GDP (BC Stats, 2021, p. 9). The ICT sector "consists mainly of small companies, with approximately 37,600 of them employing fewer than 10 people" (Innovation, Science and Economic Development Canada, 2021, p. 5). Despite the optics of a resource extraction and service economy, there is an alarming economic demand for additional emphases on STEM (Council of Canadian Innovators, 2022). Alternatively, more coordinated efforts and emphases toward STEM education could help provide the knowledge and skills capacity for change. This is contingent on plugging a "brain drain" of Canadian STEM professionals to the United States (US) (Spicer et al., 2018). At the same time, climate change is inspiring citizens and students to question Canada's economic activities and forcing a reconsideration of STEM education policy and practice. Longstanding and recent challenges to STEM education in Canada are now urgent but as explained in this chapter, the urgency is not merely economic.

Policy Contexts

Following the United States (US) Government's "Educate to Innovate" STEM policy and infrastructure launched in 2009, since the mid-2010's, Canada's federal, provincial, and territorial governments have been quite active in the STEM education policy context (Johnson et al., 2020; Shanahan et al., 2016; Weinrib & Jones, 2013). Among the federal government's 31 key initiatives are: 1) Ingenium: the Canada Agriculture and Food Museum, Aviation and Space Museum, and Science and Technology Museum which "offer sensory experiences that immerse both young and old in the many ways science and technology intersect with Canadians' daily lives;" 2) Actua: which "engages youth in inclusive, hands-on STEM experiences that build critical employability skills and confidence;" 3) Let's Talk Science: which is "committed to developing youth who are creative, critical thinkers and knowledgeable citizens prepared to participate and thrive in a complex global environment;" 4) Youth Employment and Skills Strategy: "to help young people gain the skills and work experience they need to make a successful transition into the [STEM related careers in the] labour market;" 5) Hackergal: which "inspires young women and girls across Canada to explore opportunities in coding;" and 6) MediaSmarts: which "develops digital and media literacy programs and resources for Canadian homes, schools and communities." The Actua initiative partially funds university outreach programs. For instance, at UBC the Geering Up program immerses children, youth, and teachers in summer STEM camps "to investigate engineering, science, and technology in a fun, educational and safe environment." None of the initiatives are K-12 school-based, although several fund development of STEM education resources for students and teachers (e.g., MediaSmarts).

The federal policy disconnect from educational practice is clear in the initiative for teaching coding. Although all provinces and territories maintained some form of computer science (CS) or information technology (IT) courses at the high school level for the past 40 years, none require a CS or IT course for graduation. At the same time, enrollment in electronics courses plummeted (Petrina & Dalley, 2003). Prime Minister Trudeau (2016) nevertheless seized on coding following England's and the US's policy initiatives in the mid 2010s, emphasizing that "this is really, really exciting for me because as we talk about all the different challenges we're facing, right now, right here, we're talking about one of the solutions we have." In June 2017 he allocated $50m to non-profit organizations to teach coding. Rather than deep, immersive courses in coding, shallow experiences became the norm in the late 2010s through national initiatives such as "Canada Learning Code Week" and the "Hour of Code." It is difficult to find a greater policy versus practice mismatch in STEM education in Canada.

The initiative with most potential to connect federal funding and policy with formal K-12 STEM education is "Canada 2067." Let's Talk Science (2017a) launched Canada 2067 "to catalyze a national discussion about the future of [STEM] education to help young Canadians prepare to live, learn and contribute to their communities in the economies and societies of the future" (p. 2). To boost Canada 2067's policy potential, the federal government (2019) doubled funding for Let's Talk Science to $5m per year. Most of the policy recommendations of Canada 2067 are common sense or redundant but at the same time some are unique and important. For instance, the "How We Learn" pillar recommends that "all students taking a STEM class participate in at least one inquiry-based project each year that students design/co-create" and "participate in at least one co-operative project that integrates STEM methods across multiple subjects and disciplines each year" (Let's Talk Science, 2018, p. 7). The "Equity and Inclusivity" pillar recommends that "STEM education evolves to address the specific needs of Indigenous students and to incorporate other worldviews" (p. 11; 2019a, p. 7). Teaching and learning "other worldviews" of the cosmos and nature or of tools and machines is one thing; changing economic practices and lifestyles is much more challenging. Canada 2067 reiterates that "to be successful, STEM education needs to be delivered by STEM specialists, even in the early years of education. There is also agreement that STEM teachers need to be provided with professional learning and development [PL&D] opportunities" (Let's Talk Science, 2017b, p. 5; 2019b, p. 30). Here again, the challenge is funding. The federal government has been generous in funding the production of recommendations and reports but has not allocated funds to STEM education PL&D.

The Government of Canada currently budgets about $115b to K-12 education and $313b to post-secondary education and research (Statista, 2022). The large bulk of federal STEM funding is for postsecondary education and research. A negligible fraction is allocated to K-12 STEM education. As indicated, the federal government prioritizes informal STEM education initiatives (Government of Canada, 2019, 2021a). In addition to the aforementioned, for example, the government (2019) allocates about $10m per year to its Skills Canada initiative, which supports extracurricular local and national competitions for high school students to demonstrate and refine their engineering and technology skills. STEM education is obviously a policy priority but the federal government also faces challenges of reconciling historical inequities and racism in Indigenous education (2022a). About $1.8b is annually allocated but critics argue that the government continues to underfund Indigenous education, including Indigenous STEM education (Porter, 2016). Despite the lack of targeted funding for K-12 STEM education and realities of resource and service economics, the federal government has been quick to present its budget as "Building an Innovation Economy" (2021b, 2022b). Like all countries across the world, innovation is in the context of climate change. However, in some analysts' views, the $3b total for innovation is misguided as funds targeted for postsecondary STEM funding are inadequate (Liddle, 2022). The policy emphasis on innovation targets the bulk of funds to the private sector. The "Innovation Economy" budget highlights, Liddle observes (2022), "Canada's lagging position in the global race for capital and investment to build the net-zero economy of the future." About $1.5b will hopefully "attract trillions in private capital, which would be invested in low-carbon industries, new technologies and critical supply chains." Of course, reliance on private capital can fail, as the government is well aware. In 2018 Trudeau bailed out Kinder Morgan Inc. by buying the Trans Mountain oil pipeline for $4.5b, an initial cost which actually ballooned to $17b of public funds.

Similar to governmental emphases over the past decade, private and professional agencies have increasingly agitated for policy commitments and reform in STEM education (DeCoito, 2016; Johnson et al., 2020). The Council of Canadian Academies (CCA) (2015) offered a thorough analysis of challenges to STEM education and a persuasive argument for equity, diversity, and inclusion (EDI). "Opportunities for policy responses to increase the reach of Canada's STEM capacity exist at multiple points," the CCA argues, "but early interventions [i.e., K-12] to support and expose diverse learners to a range of future education and career options have been identified as particularly critical" (p. 126). Typically focused on research and teaching at the postsecondary level, the CCA has responded to the increasing importance of K-12 STEM education. Observations and emphases are similar for policy agencies agitating for the economic interests of Canadian businesses and industries. With specific attention to students and the STEM "brain drain," the Council of Canadian Innovators (CCI) (2022) recommends funding to "incentivize post-secondary institutions to develop better experiential learning opportunities, including longer co-op placements, to establish a talent pipeline from universities to Canadian companies" (p. 4). As suggested, the proliferation of policy rhetoric has not been matched by federal funding. Johnson et al. (2020) describe the trend in Canada: "The largest efforts to improve STEM education are led by private charitable stakeholders, often in partnership with both the federal and provincial governments and also with private industry" (p. 408).

STEM Environments

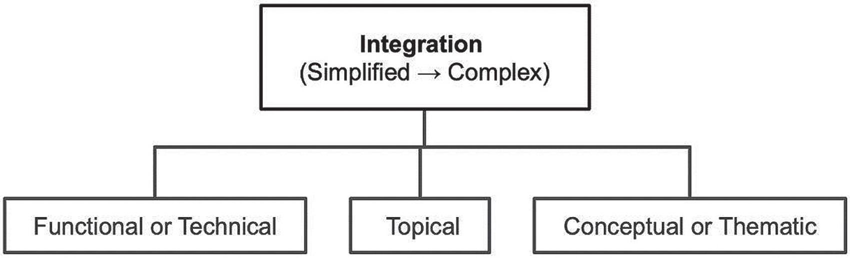
Engineers Canada (2021) has taken specific interest in policy, given questions of the place of the E in STEM education and diversity. At the core of this is a primary question: "What educational policies, programs, and practices at the local, provincial, and federal levels might permit meaningful inclusion of engineering related K-12 curriculum in Canada?" (p. 4). "To date," Engineers Canada (2021) accurately observes, "most efforts to improve STEM education in Canada have been concentrated on mathematics and science" (p. 6). By and large, engineering education is excluded from the K-12 curriculum in Canada and is often excluded from key policy initiatives. For instance, Let's Talk Science's limits its "Resources by Curriculum" for each Canadian province and territory to career, mathematics, and science education. Engineering and technology education are excluded. The most extensive policy initiative to account for the TE in K-12 STEM education is the International Technology and Engineering Education Association's (ITEEA) (2020) *Standards for Technological and Engineering Literacy: The Role of Technology and Engineering in STEM Education (STEL)*. Engineers Canada (2021) recognizes that integrating engineering activities into K-12 practices is a good first step and notes that "increasingly provinces and school districts across the country are adding technology education and design thinking principles to the mix" (p. 6). STEL draws this to a logical conclusion by formalizing the engineering and technology curriculum through learning standards beyond arbitrary integration of activities. Engineers Canada (2021) adds that neglect of the E in STEM also has implications for EDI. "The presence of engineering curricula in K-12 classrooms is important," Engineers Canada continues, "particularly for the engineering profession given that, despite a steady increase in the representation of women at all levels in STEM, women continue to be underrepresented throughout the engineering profession" (p. 6).

Along with the government, non-profit and private sector groups, and various professional societies, policy advocacy groups focus specifically on EDI in STEM education in Canada. For instance, the Canadian Black Scientists Network (CBSN) and Society for Canadian Women in Science & Technology (SCWIST) advocate for girls, women, and Black, Indigenous, and People of Color (BIPOC) diversity. Only about 22% of postsecondary engineering majors in Canada are women (Engineers Canada, 2018). Comparatively, women are about 30% of mathematics and computer science, 32% of physical sciences, and 60% of biological sciences majors in Canada (Council of Ministers of Education, 2021; Hango, 2013; Peters, 2020; Wall, 2019). Just about 25% of these women persist in the STEM workforce (Caranci et al., 2017; Frank, 2019). Women are less than 4% of the most in-demand trades in Canada (RBC, 2021, pp. 1, 8). Indigenous students represent about 1%, African / Black students 4%, and Asian and east Indian students 35%, including international enrollments, in the STEM disciplines (Finnie & Childs, 2018; Statistics Canada, 2021; Turcotte, 2020). About 27% of Canadian youth identify as BIPOC, which is increasing demands for anti-racist, equitable STEM practices. Less than half (46%) of Canadian youth anticipate working in a STEM career (Canada Foundation for Innovation, 2021, p. 13). Hence, immigration patterns of international students are important, as about 50% of STEM postsecondary students are immigrants. With at least a bachelor's degree, immigrants are "twice as likely as the native-born population to have studied in a STEM field" (Picot & Hou, 2020, pp. 13, 22; Statistics Canada, 2019). Despite the volume of policy reports and recommendations for girls, women, and BIPOC in postsecondary STEM education, the government remains ineffective in diversifying K-12 STEM education. Even basic data, such as demographics of BIPOC participation rates in STEM education are neglected at provincial, territorial, and federal levels.

STEM Education Frameworks and Systems

The conventional framework of K-12 STEM education is discrete or isolated disciplinary pipes of science, technology, engineering, and mathematics. An alternative framework is "integrative STEM," I-STEM, or the integration and mixing of these disciplines in substantive ways at optimal siphons and turns throughout the pipeline (Anderson & Li, 2020; Chesky & Wolfmeyer, 2015; Hunter, 2021; Kelley & Knowles, 2016; McGowan & Bell, 2020; Sanders, 2009; Wells, 2016). Although educators often interpret this as integrating T&E in S&M, such as through design thinking activities or projects, or S&M in T&E, through applied math and science, integrative STEM also promotes the inseparability of the four disciplines at all steps in the system. For instance, functional integration involves simplified applications of apps and tools in S&M. Less simplified is topical integration, where topics are infused with concepts from another discipline, while conceptual or thematic integration entails complex blending and clustering of three or four S, T, E, M disciplines (Figure 2) (Drake, 1993, 2020; Jacobs, 1989; Miller 1994). Integrative STEM implies that within all four disciplines are advanced concepts demanding integration and not merely tools demanding application. Persistence and retention in STEM is dependent on not only the quantity of courses but also the quality of experiences for students throughout education. Integrative STEM affects the quality of experiences in ways that individual pipes cannot. Individual STEM pipes may be indispensable to education but fairly dispensable to innovation in economics and conservation of the environment, wherein a complex integration of knowledge is necessary. One question is how to improve the quality of STEM experiences for students while minding the quantity.

Figure 2 Typology of integration



For the most part, K-12 schools across Canada use a combination of conventional and alternative frameworks for STEM education. Nearly all STEM courses involve simplified functional or technical integration and topical integration. Teachers in elementary schools are much more likely than those in secondary schools to design courses and units with complex conceptual or thematic integration of STEM. Elementary schools are somewhat interdisciplinary or transdisciplinary but the middle and secondary schools are primarily disciplinary. Nearly all public secondary schools in the country are comprehensive in that they have isolated mathematics and science courses and some form of isolated technology courses. A few schools have engineering courses, which are developed and introduced as electives by teachers taking initiative. Arguably, robotics or similar courses in many of the schools can be designated engineering courses. Requirements for graduation from high school differ across provinces and territories but there are no engineering requirements across Canada (Table 1). Informal K-12 STEM education experiences are dependent on individual parent and teacher initiative (Anderson et al., 2015; Khan & VanWynsberghe, 2020).

Table 1 Minimum high school graduation requirements in STEM in Canada

Province and Territory	Courses for Graduation (over 3-4 years)			
	Science	Technology	Engineering	Mathematics
Alberta (+ Nunavut)	4	1-2	0	2
British Columbia (+ Northwest Territories and Yukon)	2	0-1[1]	0	2
Manitoba	2	1-2	0	4
New Brunswick	1	1-2	0	1
Newfoundland and Labrador	2	0-1[1]	0	2
Nova Scotia	1-2	0-1[1]	0	2
Ontario	2	1	0	2
Prince Edward Island	1-2	1	0	1-2
Québec	1-2	0-1[1]	0	1-2
Saskatchewan	3	0-1[1]	0	2

[1]Note: Students can choose from a range of electives (e.g., arts, business, "career life") for graduation and may not necessarily choose a technology course.

Types of K-12 STEM Schools and Activities

Although there are very few in Canada, technical (i.e., vocational) secondary schools offer an alternative to the comprehensive secondary school model common to all the provinces and territories. These schools are specific to the T in STEM and specialize in functional integration or applications of mathematics and science. A trend in the early 2000s of reconfiguring technical high schools into Career Technical Centers (CTCs) looked promising, but provincial governments abandoned the investments for political reasons. Priorities shifted to reforming the postsecondary system (Usher, 2021). For instance, the BC Institute of Technology (BCIT) was granted "polytechnic" status in 2004 and Kwantlen University College was transformed into Kwantlen Polytechnic University (KPU) in 2008. For similar reasons, there are very few STEM magnet schools across Canada (Thomas & Williams, 2009). In CTCs, students simultaneously earn credits toward secondary school graduation and a polytechnic postsecondary degree. In BC in the early 2000s, four CTCs were opened: Fraser Valley (Abbotsford), Cariboo (Kamloops), Central Vancouver Island (Nanaimo), and Central Interior (Prince George) (Cormier, 2005). One convenient and cost-effective option to the technical school or CTC model entails provisioning school labs and workshops for postsecondary instructors to offer dual credit courses for students transitioning to the polytechnics. With priorities on postsecondary institutions, the Canadian government has been ineffective in providing innovative alternatives to comprehensive high schools for STEM immersion.

In spring 2018, the government launched its "Future Skills" initiative to "ensure that Canada's skills development policies and programs are prepared to meet Canadians' changing needs." The government reasons that "technological progress, new business models, climate change and the COVID-19 pandemic are changing every aspect of Canadians' lives, including workplaces and expectations at work" (Government of Canada, 2021c). The government allocated $225m from 2018-2021, and $75m per year starting in 2022. Basically, the funds support the Future Skills Council and Future Skills Centre. The Future Skills Council (2020) is especially concerned with policy "supports for under-represented groups to develop skills needed to succeed" (p. 19). For example, the Council indicates that "persons with disabilities face systemic and structural barriers to labour market participation. In 2017, about 59% of working-age adults with disabilities were employed compared to around 80% of those without disabilities" (p. 19). The Future Skills Centre (2020) "prototypes, tests and measures new and innovative approaches to skills development and training" (p. 5). The 124 innovative projects funded by the Future Skills Centre by and large engage with postsecondary institutions, the workforce, and informal education (Future Skills Centre, 2022a). Only a few are linked directly to K-12 school systems, such as the "STEM Skills and an Innovation Mindset for Youth" project ($756k over 2 years) at the Siksika

Nation High School in Alberta. "By building on the best from Indigenous tradition and STEM innovation, the project supports Indigenous youth to build resilience and skills" (Future Skills Centre, 2022b). Yet here again, the federal government has been unsuccessful as of yet to generate or inspire widespread innovation for alternatives to the conventional framework and system of STEM education.

STEM Teacher Education

An additional challenge is that K-12 schools cannot rely on teacher education for innovation or reform in STEM education. The 50 or so secondary teacher education programs across Canada are uniformly conventional. The science, technology, and mathematics education majors complete their disciplinary courses of studies in isolation from each other. No programs offer engineering education majors. Likewise, there are no secondary teacher education programs that offer an integrative STEM major, and very few have an integrative STEM course in their Calendars. In 2020, UBC renamed its two "Applied Studies in Mathematics, Science and Technology" teacher education courses to "Science, Technology, Engineering, and Mathematics (STEM) Education" I and II. However, neither version of the courses has been offered since the early 2000s. The Association of Canadian Deans of Education (ACDE), effectively a federal policy agency for teacher education, has not provided incentive or leadership for change. The ACDE's (2020) key policy document does not mention STEM, integration, or interdisciplinarity. One promising insight from the ACDE (2022) is found in its Accord on Education for a Sustainable Future: "an interdisciplinary approach is indispensable; as life is relationally interconnected and interdependent, learning must be too: curriculum cannot be siloed into distinct and disjoint subject areas since such an approach is not relational" (p. 8). The contradiction is that none of the 50 deans and directors within the ACDE have initiated secondary interdisciplinary or integrative majors, STEM or otherwise, within their respective faculties. In 2018, Memorial

University introduced a STEM elementary teacher education major (Baird, 2018). Reflecting the lack of initiative, Campbell et al.'s (2016) survey of Educators' Professional Learning in Canada found just one small initiative in STEM education, a project at Memorial University in Newfoundland (p. 8). STEM remains "siloed into distinct and disjoint subject areas" in secondary teacher education programs across Canada.

Secondary teacher education programs in Canada tend to be post-baccalaureate or diploma or consecutive, which means that students enter as credentialed specialists within a STEM discipline. In the vast majority of programs in Canada, this leads to an additional degree (i.e., Bachelor of Education). In addition to experiences in secondary schools, this basically skews student expectations that STEM in teacher education programs are cast within the conventional framework of discrete STEM subjects. A number of elementary teacher education programs offer concurrent programs, meaning that students complete their Bachelor of Education degree as an undergraduate major. Differences in teacher education requirements across Canada mean that one of the challenges is migration of teaching credentials inter-provincially or inter-territorially.

Trends and Issues in STEM Education

Issue 1: Isolated STEM subjects

As described, K-12 STEM education practices across Canada are based on a framework of discrete subjects. There are activities and units that challenge students to integrate the four STEM subjects but integrative STEM courses are rare, especially in secondary schools. Are the four STEM subject boundaries more important than the interdependencies?

Trend 1: Indigenous ways of knowing and learning

Persistent isolation of STEM subjects in K-12 schools and teacher education programs is challenged by policy recommendations for the *First Peoples Principles of Learning* (*FPPL*) (First Nations Education Steering Committee, 2006/2008). The FNESC (2017) explained, "with the increased inclusion of First Peoples' content… there is a need to incorporate unappropriated First Peoples' perspectives across the curriculum." In response, educators and researchers across Canada have taken the FPPL somewhat seriously. The second *FPPL* has common agreement but application has escaped practice in secondary schools and teacher education in Canada: "Learning is holistic, reflexive, reflective, experiential, and relational." This and the balance of FPPL were derived from historical Indigenous practices across the world, including Hualapai, Māori, Navajo, and Indigenous communities in Canada. For example, Reedy (2000, pp. 159-160) and Watahomigie and McCarty (1994, pp. 27-28) describe the learning principles practiced in Māori and Hualapai communities. It is nearly impossible to reconcile this second principle— learning is holistic— in the isolated STEM disciplines in secondary schools and teacher education programs in Canada. Leddy and Turner (2016) summarize the challenge: holistic learning "defies older reductionist ideas about meaning making and curricular content" (p. 62). To be sure, one of the more profound challenges to status quo STEM education across the world is "Traditional Ecological Knowledge and Wisdom" (TEKW) (Nashon & Madera, 2013; Turner et al., 2000).

Issue 2: STEM education is not very accessible and accommodating

Federal, provincial, and territorial governments in Canada are pressured to facilitate an increase in the number of STEM students for two reasons. First, economic forecasts and representatives from business and industry anticipate an increasing demand for STEM workers over the next few decades. The current demand may be low at the moment but will soon intensify, especially if the government is serious about nurturing an innovation economy to supersede the resource sector. Second, cultural and social activists are pressuring governments to diversify postsecondary STEM disciplines and the workforce.

Trend 2: EDI in STEM education

Policies for the "STEM pipeline" necessarily address quantity (of students, courses, etc.) but it is the quality of integrative experiences that tends to draw students into K-12 STEM education and retain them throughout. This is often described as a crisis, wherein a full demographic enters in elementary schools but only the drip of a few are retained or survive at the end of postsecondary, despite vast resources throughout. As Wall (2019) reports:

> A commonly used metaphor is that of "leaks" in the STEM "pipeline," with women [or BIPOC] being lost from the pipeline at various different points: between high school and undergraduate studies; over the course of undergraduate studies; between undergraduate and graduate studies; and between degree completion and the workforce. (p. 2)

In the United States, the President's Council of Advisors on Science and Technology (2010) observed that "some of the problem, to be sure, is attributable to schools that are failing systemically; this aspect of the problem must be addressed with systemic solutions. Yet even schools that are generally successful often fall short in STEM fields" (p. vi). Why is that? Why do successful schools "often fall short in STEM fields"? Although the pipeline metaphor has various shortcomings (Garbee, 2017), problems attracting and retaining students in STEM or renovating the STEM pipes and pipeline are without a policy solution in Canada. As emphasized in this chapter, integrative STEM education is an extremely relevant response to the challenge of discrete pipes in contrast to Indigenous ways of knowing and learning. Resolving the challenge of recruiting and retaining BIPOC students in STEM education and careers is a qualitative problem.

Issue 3: MST (mathematics, science and technology) pre-exists as core to STEM

The roots of STEM are often dated to the 1940s, but interdependencies among the four disciplines long predate WWII. Prior to explicit STEM education initiatives of the 1990s were MST initiatives (Petrina, 2021). During the 1980s and 1990s, technology educators were especially influential in promoting the value of MST and project-based learning as a natural integrator (Foster, 1994). Engineering was accommodated to create STEM, which continues to challenge educators and researchers to rethink MST configurations.

Trend 3: Expanding the STEM cluster

If secondary schools and teacher education programs cannot integrate the four disciplines in complex ways to innovate, it is that much more challenging to integrate five or more disciplines. A common iteration on STEM adds an A for Art or Arts to create STEAM, which begs the question of adding the D from Design to create STEAMD (Petrina, 2021). Like integrative STEM, STEAM has found its broadest appeal in Canada in elementary schools and extracurricular enrichment programs (Bertrand, 2019; Han et al., 2017). STEAM has also found appeal within Indigenous communities, symbolized most notably in the Six Nations Polytechnic (SNP) STEAM Academy in Ontario. Funded by the federal government's Actua initiative, the SNP Academy "integrates and applies the STEAM subjects to meaningful and complex questions, problems, or challenges, that guide students' inquiries to ask thoughtful questions, research to discover answers, and apply what they have learned to problem solve" (SNP, 2022). STEAM and other iterations on STEM are reminders of the importance of culture and the interconnectedness of knowledge.

Providing alternative frameworks and critiquing STEM are important to holding K-12 and teacher education to account for regressive or unsustainable conventions and stagnation (Bencze, 2017; McComas & Burgin, 2020; Petrina, 2014; Rodríguez, Alsop et al., 2017). As indicated at the start of the chapter, Canadian researchers and teacher educators have been keen to demonstrate the viability of STEM as more than four discrete disciplines (Marotto & Milner-Bolotin, 2018; Milner-Bolotin & Marotto, 2018). On the surface, Science, Technology, Engineering, the Environment, and Mathematics (STEEM) has great potential considering the devastating effects and implications of climate change in Canada (Bigloo et al., 2021; Dierking et al., 2013). With this in mind, Cole and O'Riley (2017) suggest transforming STEM to ESTEEM, or "*ecojust-socio-transspecies-equivalency-engendering-mutuality*, foregrounding the natural world as main-stream rather than transnational corporate consumerism; adding an 'e' for *ecojust* signals that the ecological responsibility is to be foregrounded" (p. 26). Banack (2018) adds three E's, ethics, environment, and ecology, to make the case for STeeeEM as "an effort perhaps to oppose STEM galvanization, however more so towards relevance of *where* STEM learning occurs and STEM *usefulness*" (pp. 43-44). Some scholars advocate for adding an additional E for Entrepreneurship to account for the vast practices of creativity, production, and exchange necessary to sustain lives and families across the majority world (Ezeudu et al., 2013; Kelly, 2017). With this critical sense of Business, the Environment, and Design, STEAM-BED has potential. Since the Covid pandemic began in 2020, researchers have increasingly added health-related disciplines and medicine to STEM, creating STEHM or STEM-H and STEMMed (Code et al., 2022). Similarly, with economic demands, one might accommodate a second T for Trades to create STTEM. Early learning educators add R for Reading to advocate for STREAM (Clements et al., 2020). It is quite effective to add a second M for media to create STEMM. Perhaps STrEAM is the best of all if "r" stands for reserved, indicating a placeholder for any number of additional disciplines or practices.

Instead of trying to insinuate a role by expanding the STEM cluster, what are the alternatives for the balance of disciplines? Since early medieval times, the

Liberal Arts (*artes liberales*) referred to clusters of disciplines as well as ways of thinking, and since the 1850s the humanities (*literae humaniores*) was a cluster of languages and literature, ancient history, philosophy, and theology. Established in 1965, the US National Endowment for the Humanities (1985) was quite expansive in including disciplines in the humanities: "history; philosophy; languages; linguistics; literature; archaeology; jurisprudence; the history, theory, and criticism of the arts; ethics; comparative religion; and those aspects of the social sciences that employ historical or philosophical approaches" (p. 2). The sciences have been clustered as natural sciences and physical sciences since the late 1700s, social sciences since the 1850s, and behavioral sciences since the 1930s. Clustering disciplines is co-extensive with the history of education. As a parallel for STEM, the Government of Canada (2021d) clusters Business, Humanities, Health, Arts, Social Sciences, and Education (BHASE). Currently resolving the challenge of clustering business, home economics, and technology in schools, in 2015 the BC MoE (2022) introduced Applied Design, Skills and Technologies (ADST). This influenced an introduction of new courses, such as Industrial Coding & Design and Mechatronics. Yet while profiling ADST, in 2018 the BC MoE eliminated its STS curriculum and associated course, Science and Technology 11, which was introduced in 1986.

Issue 4: Too many alternatives to STEM

At about the same time that MST was popularized in K-12 schools and teacher education, STS was introduced as a viable subject. STS was a reminder of the importance of social studies, which is excluded from the conventional STEM configuration. In all social studies curricula across Canada, there are expectations that S&T constitute interesting units; however, this is quite minor. In most grades and schools, these expectations are allocated to history. For instance, *History Uncovered: Canadian History since World War I*, a popular high school textbook, does not have a separate chapter but instead disperses a bit of S&T throughout (Armstrong et al., 2014).

Trend 4: STS and STSE considered

STS in K-12 schools and teacher education seems to have been displaced by a regression to discrete STEM disciplines in Canada. From the 1980s through the 2000s, STS gained a foothold in Canadian K-12 schools and teacher education programs (Aikenhead, 2000). Aikenhead's (1991) textbook for secondary students, *Logical Reasoning in Science & Technology*, helped teachers embrace STS, and his policy advocacy was influential across the country. STSE was a reminder of the significance of the environment (Fuchs & Tan, 2022; Harris, 2017a, 2017b; Pedretti & Nazir, 2011). Unlike BC and the other provinces and territories, only the Alberta (2014), Québec (2011/2021), and Ontario (2007) MoE's retain STS as a subject. The Council of Ministers of Education (CMEC), a federal policy agency for K-12 schools, has not made a substantive statement on STS since 1997. STS and STSE appear to have been "relegated to the margins" across a balance of provinces and territories in Canada (Nashon et al., 2008; Waddington & Imbriglio, 2011). Applied academics, an initiative preceding STEM, met a similar fate in Canadian schools (Hepburn & Gaskell, 1998). Ironically, the majority of universities in Canada have active STS programs (i.e., courses, degrees, etc.) at the undergraduate and master's levels (Cornell University, 2015; UBC, 2022). While it is often said that "the history of STEM education reform is littered with failures," what is S, T, E, & M if not a record of learning from failure (Petrina & Dalley, 2003; Tobias, 1992, p. 90)?

Issue 5: Full membership in clusters is not easy

To say that education is a history of clusters is not to say that all disciplines are recognized as equals or given a balance of responsibility in the schools and postsecondary institutions. At various times, some within a cluster may assume an importance that shadows that of others. In the social studies cluster, for example, civics, geography, and history have assumed importance over the balance of anthropology, economics, political science, and sociology. In

Canadian elementary and secondary schools, it is rare that any of these four are included or required. STS courses challenged social studies to account for science and technology.

Trend 5: Resolving T&E in STEM

There are various facets to the neglect of T&E— Technology & Engineering— in STEM across Canadian secondary schools (Hill, 2009). One facet is the exclusion of a required curriculum. As indicated in Table 1, in five provinces and two territories, students can graduate without completion of a technology course. None of the provinces and territories have an engineering requirement. Given that design is central to engineering and technology, a number of Canadian students can attend 12 years of school and graduate without a formal, substantive design experience (Banks & Barlex, 2021; de Vries, 1997; Petrina, 2021). Given the segregation of course selection, girls or young women are the majority graduating from many Canadian high schools without a technology course (Braundy et al., 2000). This has ripple effects back through the elementary schools in signifying priorities as parents and students plan and then forward to postsecondary schools, everyday cultural and social life, the environment, and scenarios for a predominantly resource and service economy. The inconsistency is disconcerting but as affirmed in the STEL, this is not unique to Canada.

Too often, however, what passes for “STEM education” involves an unbalanced focus on science and mathematics, with marginal attention to technology and engineering. This is likely due in part to the fact that science and mathematics are considered core subjects in most schools, while technology and engineering, when offered, are typically electives (ITEEA, 2020, p. 5).

One might argue that most Canadian students perform well enough on measures in the Programme for International Student Assessment (PISA) of reading, mathematics, and science proficiency, and in the Trends in International

Mathematics and Science Study (TIMSS), so why rock the boat (O'Grady et al., 2019; O'Grady et al., 2021)? The majority of grade 8 students achieved average results on the Pan-Canadian Assessment Program (PCAP). There are no measures of performance in engineering and technology education so the status of Canadian students is unclear.

A second facet is an oversight of engineering and technology in popular large-scale assessment enterprises across Canada (Petrina & Guo, 2008). The Pan-Canadian Assessment Program (PCAP) (2021) and TIMSS (O'Grady et al., 2021) simply assess S&M in STEM and overlook T&E. The International Association for the Evaluation of Educational Achievement (IEA), which sponsors TIMSS and a range of other large-scale international assessments simply does not have a scale for engineering and technology. The IEA's (2022) International Computer and Information Literacy Study (ICILS) is helpful but addresses just a small fraction of engineering and technology. Comparatively, the STEL have yet to be transformed into a large-scale international assessment. Canada did not participate in previous ICILS in 2013 and 2018 and will not participate in 2023. A third facet is the failure of policy, research, and theory to influence the implementation of integrative STEM courses and programs in secondary schools and teacher education programs. Secondary STEM education in Canada remains established on a framework of discrete courses established in the late 1800s (Linn et al., 2016). This is only partially due to testing regimes and matriculation requirements for postsecondary admission.

A fourth facet is that many educators and researchers across Canada and the world seem to believe in a fiction that "technology has no content" or "technology is not a discipline." Basically, the world has Canada's McLuhan (1960, 1962, 1964) to blame for this fiction, but it was not his fault. Historically, it was readily apparent and accepted that technology inherently has content and is an academic discipline, field, or subject (Petrina, 1998). Bigelow (1829) popularized the formal study of technology and helped found the Massachusetts Institute of Technology (MIT) (1860/1861) on the principle that technology was an intelligible subject. Québec's Ecole Polytechnique was founded on the same principle in Montreal in 1871 (Rabkin & Levi-Lloyd, 1984). Like mathematics and science education, courses, experiences, and texts for K-12 and postsecondary students demonstrated the study of technology across the world through the late 1800s and early 1900s. The sentiment that "science is neutral" became widespread at this time primarily in defense of the confrontation with religion. The sentiment that "technology is neutral" was coincidental with the rise of motion pictures at this time. Military and Nazi science and technology through WWI and WWII made the sentiment suspect. Still, a vast majority of educators, policy-makers, and researchers focused on the content of the scripts and performances of motion pictures to the exclusion of the content of technologies. For example, upon introducing *The Content of Motion Pictures*, an influential collection of studies, the editor asserted that "if children and adults are being affected by what is shown on the screen, it is important that an analysis of motion picture content be made to show the nature of the stimuli that are producing these changes" (Dale, 1935, p. 1). The implication was that the motion picture equipment, media, or technologies were neutral or transparent and it was the script and performance content that shaped experiences— technology itself has no content. This emphasis continued in courses and studies of radio and television through the 1950s. Using Schramm et al.'s (1961) *Television in the Lives of Our Children* as an example, McLuhan (1962) critically reported that "they assume that apart from the 'program' or 'content' TV is a 'neutral' medium like any other" (p. 145). He identified the trend as a distraction from reality or a fiction reinforced and taught across education, including teacher education.

Somewhat sarcastically, McLuhan concluded that "the 'content' of any medium is always another medium" (1960, p. 14; 1964, pp. 23, 266). With his example of electric light, this is restated as "the 'content' of any technology is always another technology" (1964, pp. 23-25). This "'illusion' of content, he insisted, “syphons off all attention from the forms and effects of the media” and technologies (1960, p. 14). He chastised RCA Chairman David Sarnoff, who proclaimed in 1955 that we are “prone to make technological instruments the scapegoats for the sins of those who wield them. The products of modern science are not in themselves good or bad; it is the way they are used that determines their value” (1964, p. 26). McLuhan (1964) pointed out the troubling conclusion from this logic: “Firearms are in themselves neither good nor bad; it is the way they are used that determines their value” (p. 26). “Our conventional response to all media,” he continued, “how they are used that counts, is the numb stance of the technological idiot. For the ‘content’ of a medium is like the juicy piece of meat carried by the burglar to distract the watchdog of the mind” (1964, p. 32). Educators and researchers nonetheless repeated this cliché in response to teaching machines through the 1960s and personal computers or devices from the 1970s to the present— ‘the content of any medium or technology is unimportant.’ “It is important to remember that technology is not a subject.... Just as reading is content-free, so is technology,” Earle (2002, p. 11) assumes. Making a case for STEEM, Kelly (2017) surmises that technology is “not a discipline in the strictest sense” (p. 35). So if technology has no content, how could it be a discipline? If engineering and technology have irrelevant content next to mathematics and science, why inflate them to STEM? If engineering and technology are merely tools in service of mathematics and science, is there really anything to STEM at all?

To redress oversights, a key consideration for STEM educators, policy-makers, and researchers in Canada is *STEL*, which “describes what the content and practices of technology and engineering education should be in Grades PreK-12” (ITEEA, p. ix). For the most part, Canadian K-12 schools draw their curriculum standards from international initiatives and large-scale tests, such as PCAP, PIRLS, PISA, and TIMSS. The pan-Canadian initiative for Benchmarks of Historical Thinking (Peck & Seixas, 2008; Seixas, 2009) has not been matched by a similar initiative for engineering and technology education in Canada. There is really no need for this given the comprehensiveness of *STEL* and its predecessors, such as *Standards for Technological Literacy* (ITEEA, 2000; National Academy of Engineering, 2010). *STEL* reiterates a basic principle made clear in *STEM[4]: The Power of Collaboration for Change*, namely, "STEM education should advance the learning of each individual STEM discipline" (Advance CTE at al., 2018, p. 3; ITEEA, 2020, p. 17). Indeed, we are always reminded that "standards are meaningless if not accompanied by a commitment to the implementation of strategies that enable all students to meet them" (Stewart, 1991, p. 72).

Conclusion

This chapter has provided an overview and details of STEM education in Canada. Like other countries, the Canadian government anticipates that STEM will be a catalyst for economic and cultural change. However, federal policies and funding for K-12 STEM education have had little effect on practices in schools and teacher education. These policies and programs emphasize post-secondary STEM on one hand and informal STEM education for children and youth on the other. The federal government's investments in postsecondary STEM education and research are effective but have not generated the "pull" scenario for K-12 STEM educational change. For instance, five provinces and two territories do not have technology course requirements for graduation from high school. None of the provinces and territories have an engineering requirement. The reasons for these oversights may be conceptual or philosophical, as some educators and researchers believe that technology itself has no content or is not a discipline comparable to mathematics and science. The vast majority of non-profit, private sector, and professional society policy recommendations reinforce the federal government's lead. Integrative STEM education, a potential catalyst recommended by a range of researchers and teachers across the world, has also not had much influence on K-12 schools and teacher education in Canada. As we might expect, most of the integrative STEM practices are found in elementary and middle schools. By and large, secondary schools in Canada are characterized by individual STEM disciplines or pipes. Hence, it has been extremely challenging for the Canadian postsecondary education system to accommodate BIPOC students in STEM. If educators and researchers take the FNEC's (2006/2008) *FPPL* seriously then perhaps changes reflective of holistic learning and integrative STEM are on the horizon. Iterations on STEM, such as STEAM, STEEM, and STEM-H provide additional challenges across the educational system in Canada.

Canada is at various crossroads and one of these is STEM education. Canadians are currently mortgaged well beyond their means (i.e., 120% of disposable incomes) as inflation skyrockets to record highs, incomes stagnate, and inequality grows. The gig economy is the fastest growing sector, with 1/10 Canadian adults now freelancing or contracting for work (Payments Canada, 2021). Climate change is having immediate effects with Canada warming at twice the rate of the balance of the world (Bush et al., 2020, p. 34). A threat to nature, this is also a short- and long-term threat to community and individual health and livelihoods, culture, economics, and education. There is a profound sense, from educators, politicians, and parents to students, that STEM education has to change but there are also profound disagreements over the how, what, and why of necessary changes. This chapter addressed and critiqued key issues and trends in STEM education in Canada to facilitate potential changes. The chapter began by acknowledging the "STEM in Education" partnership with Australia and China, which is symbolic of the important insights and work of STEM educators and researchers locally and across the world. Like the challenge of STEM itself, we are better united than divided in the world.

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Status and Trends of STEM Education in Finland

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Abstract

STEM education is an approach that has affected all countries of the world in recent years. Undoubtedly, one of the countries exposed to this effect is Finland. In this chapter, the status and trends of STEM education in Finland will be discussed. In this context, the chapter consists of some main titles and sub-titles. The status and trends of STEM education in Finland are discussed under the following main headings: the Finnish Education System, the National Level STEM Education Development Project in Finland, the National Core Curriculum Emphases on STEM Competences, the Phenomenon-Based Approach to Education, including STEM Education, Emphasis on Learning of Transversal Competencies, Emphasis on Science and Engineering in the Middle School Curriculum, and Possibilities for Informal STEM Learning in Finland. In addition, the main title of possibilities for informal STEM learning in Finland consists of some sub-titles such as entrepreneurial education, student camps, cultural events (festivals, competitions, TV series, etc.), science centers, and museums in Finland. STEM education characteristics are revealed in the Finnish curricula in three significant ways. First, science and engineering process skills introduced in the curricula require the concretion of science with mathematics, engineering, and technology. Second, the subject-specific curriculum emphasizes students' engagement in science inquiry and technology-related problems. Third, the middle school curriculum emphasizes the learning of transversal competencies.

Keywords: informal STEM learning, STEM career interest, STEM competences, STEM projects, transversal competences

Introduction

Countries that want to make progress in the technology industry and overcome or solve challenges such as climate change, and improve science and engineering research and survive in the global competition environment have been looking for innovative pedagogical approaches such as STEM education in their education policies (Corlu et al., 2014). The concept of STEM, which has been created by combining the initial letters of Science, Technology, Engineering, and Mathematics, is defined in different ways by researchers conducting studies related to the topic (Boğar, 2021). However, the most common characteristic in the definitions of STEM is the integration of different STEM disciplines in order to solve complex problems (Sanders, 2009). This emphasis is also present in the Finnish primary and secondary curricula as outlined later in this chapter. The Finnish curricula emphasize Mathematics and Science as core subjects but separately, and Technology and Engineering as a part of science and a part of handicrafts. However, each STEM subject is taught separately since the beginning of lower secondary school (grade 7-9) with the expectation that the combination of disciplinary knowledge will be implemented. Consequently, the first characteristic of the Finnish National Core Curriculum is an emphasis on STEM competence. The second characteristic emphasized in the literature and recognized in Finland is phenomenon-based STEM integration, or use of real-world, rigorous, relevant phenomena as a starting point for learning (Tsupros et al., 2009; Vasquez et al., 2013). In line with this second characteristic is the emphasis on inquiry or project-based learning as a pedagogical approach. The third characteristic is the emphasis on learning transversal competencies as a part of STEM education. The fourth internationally recognized characteristic of STEM education which is also and emphasized in Finnish education is the emphasis on science and engineering careers in the middle school curriculum as a part of STEM education (National Academy of Engineering and National Research Council [NAE & NRC], 2014). Finally, in addition to STEM education at school, there are several possibilities for informal STEM learning in museums, university labs, and camps. We will analyze these five views on Finnish STEM education in this chapter. However, we start by introducing the Finnish education system. Then, we will continue with national-level STEM education projects and networks to support STEM learning in Finland.

Finnish Education System

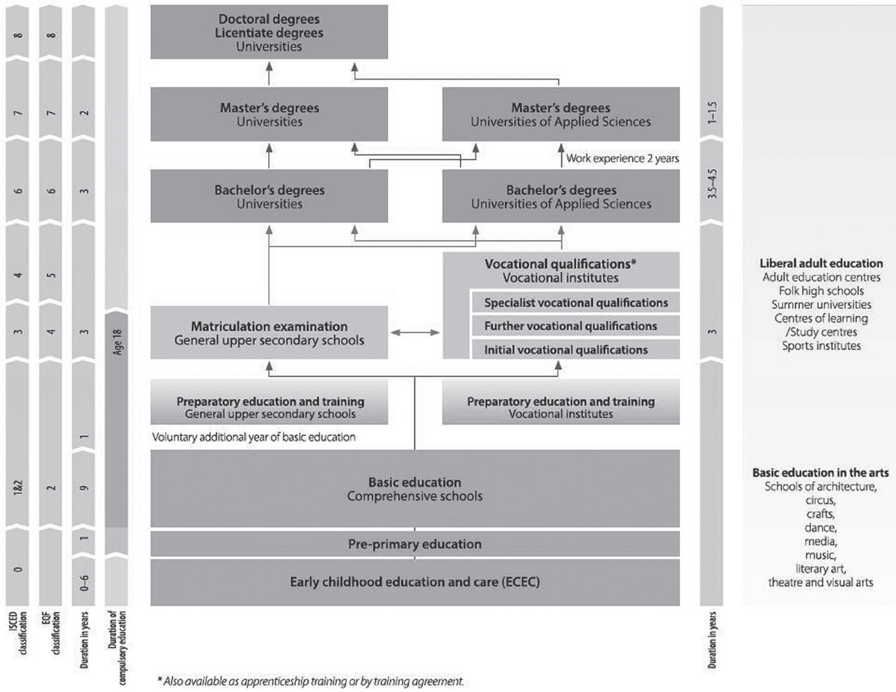
Internationally, the Finnish education system has drawn attention because Finnish students have achieved high scores in the PISA science, mathematics, and reading literacy sections, and are typically ranked among the five highest performing countries in the Organisation for Economic Co-operation and Development (OECD). Moreover, the differences between students' performances are relatively low compared to other OECD countries (OECD, 2010). However, the performance gap between girls and boys was the largest across OECD countries in 2018: reading: 546 (girls), 485 (boys); mathematics: 510 (girls), 504 (boys); and science 534 (girls), 510 (boys). Although Finnish fourth grade students performed the best in TIMMS among the Nordic countries, there was a decrease in learning outcomes (Reimer et al., 2018).

The basis of the Finnish education system, which is considered attractive by other countries and accepted internationally, is constituted by equality and justice concepts emphasized in every stage of education (Lavonen & Salmela-Aro, 2022). Equality and justice concepts in the Finnish education system mean that all students until the age of 19, until they start higher education, have the right to use medical care services, transportation, digital tools (laptops, etc.), course books, and school meals free of charge (OECD, 2019a). In other words, from pre-school education to higher education, education services are completely free of charge in Finland. Besides, Finland does not have private schools, and students go to the schools which are close to their homes; this is an indication of every student being presented with equal educational opportunities, which is another primary element of the Finnish education system (Sahlberg, 2007).

Structure of Education in Finland

In Finland, before primary education students receive early childhood education for one year. Compulsory education in Finland comprises one year of early childhood education, six years of primary education and six years of secondary education (Finnish National Agency of Education [FNAE], 2022). After ten years of education, half of the students in Finland prefer to receive education in common high schools, while the other half prefer to receive education in vocational high schools. Both education types generally take three years (Finnish National Board of Education [FNBE], 2015). Students who complete common high schools in Finland take a national competency exam, which is held twice a year, to determine whether they have acquired the knowledge and skills implemented in the high school curriculum (Morgan, 2014; Ruzzi, 2005). This exam is also used as an entrance examination in higher education. Therefore, in Finland, passing to higher education from high school education is not a relatively easy process; on the contrary, it is quite a difficult process (Salmela-Aro, 2020). Some of the difficulties are stated as follows: going to a higher education institution requires a quite eliminative acceptance process. Students who are interested in STEM (Science, Technology, Engineering, and Mathematics) tend to have low motivation, and students' interest in STEM fields diminishes gradually, with most students not choosing STEM fields (OECD, 2019b). In Finland, applied universities and traditional research universities constitute higher education institutions, and these institutions are considerably autonomous in terms of planning their study programmes (Sahlberg, 2015). Figure 1 depicts the Finnish educational system.

Figure 1 Finnish education system (URL-1)



In Finland, all teachers need five years of university studies which include pedagogical studies, offered by faculties of education (Jakku-Sihvonen & Niemi, 2006). Primary or elementary school teachers instruct from 1st to 6th grades, and secondary school teachers instruct from 7th to 12th grades (Niemi et al., 2016). Secondary teachers, including teachers who teach mathematics, physics, chemistry, biology, and craft science, take their subject studies at the faculty of science. The universities give qualifications for the teacher profession and no external accreditation is needed.

According to education policy, teachers have an autonomous role in the classroom (Niemi & Lavonen, 2020). This approach is known as the Bildung-Didactics approach, and emphasizes both teachers' autonomy and their pedagogical freedom (Autio, 2014). Autonomy of teachers enables teachers to organize their lessons as they wish, design digital and physical learning environments in their classrooms, evaluate their students' and their own learning, and choose various teaching materials such as course books (Lavonen & Salmela-Aro, 2022). This fact indicates that teachers have a prominent role in the Finnish education system (Lavonen, 2020; Lavonen & Salmela-Aro, 2022). Additionally, teachers in Finland are strongly attached to their professions and perform their jobs willingly (Niemi et al., 2016).

Besides teachers' autonomy in Finland, schools and municipalities are also autonomous (Simola, 2005). In the Finnish education system, the judgment for defining, organizing, and even conducting the content belongs to schools and municipalities. The Finnish education curriculum consists of two curricula, one is the National Core Curriculum including basic content and purposes, and the other is a local curriculum, which is constituted by the schools and municipalities by taking into consideration local needs and the National Core Curriculum (Lavonen, 2021). Besides, the National Core Curriculum is revised every 10 years (Lavonen, 2021). During the curriculum revision process, teachers, pedagogues, principals, teacher trainers, and various shareholders work in cooperation and state their thoughts freely. Moreover, these works are open to everyone's access via communication means such as social media and various discussion forums to follow a transparent process (FNBE, 2014). In this context, the latest curriculum is the National Core Curriculum which was revised in 2014 (FNBE, 2014; Wang et al., 2018).

Higher education in Finland is free for students, and studies are financed by the Ministry of Education and Culture. The government agrees with universities on the number of degrees based on the needs of society and the labor market. In 2021 there were altogether 56,000 students (36% of all students) in STEM studies and 14,000 (8.5%) in health and medical studies in Finnish universities (Statistics Finland, 2022a). In applied universities the corresponding numbers were 53,000 (34%) and 46,000 (30%) (Statistics Finland, 2022b). Although the monitoring has been reliable, the technology industry has argued that they will need 130,000 new STEM experts within 10 years, about 13,000 annually (Finnish Technology Industry, 2022).

National Level STEM Education Development Projects in Finland

Development projects conducted at a national level are one possibility in Finland to emphasize and develop STEM education. As an example of these projects, LUMA-SUOMI, a six-year project which was conducted between 2013-2019, can be presented. It is a project worth 5 million euros and was assisted by the Ministry of Education and the Ministry of Cultural Affairs. Its first aim was to improve students' natural sciences, technology, mathematics learning, and creativity skills. Its second aim was to incorporate shareholders including teachers, school administrators, and parents into the process while improving students' natural sciences, technology, mathematics learning, and creativity skills. Within the scope of this project, various education materials were developed and these materials were published in Finnish and Swedish on the project's website (URL-2). One interesting STEM education projects is StarT. The StarT development project is a project for universities which supports cooperative and interdisciplinary learning. The most prominent aim of this project is to promote different universities to write various theses and to publish scientific articles at an international level by discussing different themes (themes that are related to STEM topics) (URL-3). Some important international studies were published within the context of this project (Aksela & Haatainen, 2019; Viro et al., 2020).

There have been several in-service training projects in STEM education. One example is "Matematiikan opetuksen and oppimisen täydennyskoulutusohjelma [In-service education program in Mathematics education]" between the years 2018-2019. This project involved in-service education of 15 of the European Credit Transfer and Accumulation System (ECTS) for teachers working from preschool to middle school education in Mathematics. Including both part-time and online courses, this project aimed to improve teachers' pedagogical and mathematical skills. In this context, in-service education for the teachers was free of charge. Besides, this development project was funded by the National Education Agency (URL-4).

In Finland, some of the projects related to STEM are within both the development and research project scope. As an example of these projects, we can present a project which was conducted within the scope of the LUMA FINLAND program from 2014 to 2019 to make science, mathematics, and computer science learning more engaging for students between the ages of 3 and 6. The project which was conducted by Helsinki University was also supported by the Finnish Ministry of Education and Culture. As the research method of this project, a design-based research method was used, and under the scope of the project, pedagogical innovations and quite authentic solutions were revealed (URL-3). Besides, based on this project, theses were written and international articles were published (Vartiainen & Aksela, 2013; Vartiainen & Aksela, 2019).

Some projects related to STEM fields are just within the scope of the research project in Finland. "Laboratory of Co-Inquiry, Co-Design, Co-Teaching and Co-Regulation (Co4-Lab)" project can be provided as an example of a research project in Finland. As a project that is long-term, and is based on repetitive research cycles and pedagogical innovations, one of its most prominent aims is to support maker applications conducted both at schools and by the teachers in their classrooms. Thus, students will be able to construct their own knowledge and produce their own works. In addition, this project not only supports maker applications but also supports coding, 3D, and robotics applications. These applications are either directly or indirectly related to STEM fields (URL-5).

Networks to Support STEM Education in Finland

In Finland, there are major networks aiming to improve students' and teachers' knowledge and skills related to STEM fields. The most prominent of these Networks in Finland is "LUMA Centre Finland." This network has two major aims. Its first aim is to improve both the lifelong learning and research-based teaching of the teachers working at different education levels. The second aim is to both motivate the students at different levels in science, mathematics, and technology learning (URL-6). Another important network in Finland is "The Innokas Network." This is known as a teacher network in the most general sense. It aims to help teachers gain skills by advising schools in different regions in Finland, and by organizing events and training (URL-7).

National Core Curriculum Emphasizing STEM Competences

The middle school STEM-oriented curriculum is part of the curriculum of different school subjects in the National Core Curriculum for Basic Education. However, STEM as such is not mentioned because the Finnish tradition has been to have a subject-oriented curriculum. The curriculum of the Finnish middle school science is designed as an amalgam of three different curricula, biology, physics, and chemistry; besides, the course is offered by a secondary school teacher whose expertise is in two different disciplines, for example, chemistry and biology, chemistry and mathematics, physics and mathematics, or geography and biology. Mathematics is introduced as a separate school subject and has links to several school subjects, not only STEM subjects. Engineering and technology are taught as a part of science subjects and as a part of craft subjects (Lavonen, 2021).

According to the critical examination of the STEM skills shortage in European countries, Dobson (2013) recognized that the number of studies in the STEM subjects in Finland is higher than in most countries in Europe. The underlying reasons behind this fact cannot be explained by a single factor; rather it may be the result of the country's broad historical and cultural background as well as the government's beneficial policies on education and equal opportunities. Since STEM appeals to a great extent to the educators in Finland's education system, educational issues related to STEM are not a matter of debate there. Rather, other educational issues such as teaching and learning foreign languages are a matter of concern for them. On the other hand, STEM has been mainstreamed through the Finnish education system rather well.

The Finnish science curricula strive to achieve a balance between *knowledge within science and knowledge about science* (Wang et al., 2019a). The aims for teaching are grouped in three areas in the Finnish middle-school biology, chemistry, and physics curricula. These areas are (1) meaning, values, and attitudes related to science; science learning and science careers; (2) learning of science research skills or scientific practices; and (3) use of biology/chemistry/physics knowledge in various situations (FNBE, 2014). One of the aims of a science curriculum is defined as the "learning of science research skills"; however, a similar depiction, "scientific practices" appears in the Next Generation Science Standards as well (Next Generation Science Standards [NGSS], 2013), which refer to skills that students should attain such as identifying problems and posing questions, devising and conducting investigations, examining and commenting on data, making explanations, and producing solutions. Examples of the Finnish science, mathematics, and craft aims are given in Table 1. The amount of text in each subject-specific curriculum is limited, and the core content and aims of each science subject are introduced in about two pages.

There has been a long tradition of reducing the number of concepts and content areas in middle school science curricula in order to have enough time to learn research skills or scientific and engineering practices (Lavonen, 2007).

For example, six core ideas, namely "Physics in Society," "Interaction and Motion," "Scientific Inquiry," "Electricity," "Physics Shaping the Worldview," and "Physics in Your Own Life and Living Environment," that students must learn are introduced in the middle school physics curriculum (Lavonen, 2021). This means that only two traditional content areas of physics are emphasized: the basics of Newtonian mechanics and electricity. As a part of these subject areas, technological devices and processes are emphasized. Moreover, students build up devices and systems, such as electric motors. A teacher can decide at what level and how deeply he or she introduces the topics and applications related to thermal physics, waves, optics, and modern physics.

Engineering and technology are part of science and craft studies. Finland has a long history of compulsory handicraft education in the context of hard materials such as wood and metal, and in the context of soft or textile materials in Finnish middle schools. The new National Core Curriculum combines these two orientations into common craft education, and emphasizes the learning of technology and engineering in the context of soft and hard materials and technological systems such as robots. The craft curriculum emphasizes technological and engineering knowledge, skills, and attitudes (Autio, 2016) and has oriented from craft products to the process of crafting (Kokko et al., 2020). The concept of craft in the Finnish context refers to handmade artifacts and to the processes of making, and many socio-cultural and historical aspects are connected to them (Kokko et al., 2020). During the craft education lessons, students are required to plan their projects out, often in groups, before they begin to build them. The craft classrooms and workshops are equipped with tools such as manual tools and more sophisticated tools like laser cutters and knitting machines, that are needed for working with different materials such as wood, metal, and plastics textiles. The workshops are similar to maker spaces in the United States. This recent approach to the relationship between science and handicraft is linked to the increasing demand for employees who are capable of critical thinking and are resourceful enough to eliminate a series of problems (Autio, 2016). Among the researchers in craft education, there is a clear orientation from traditional craft education to research-based STEAM education (where A stands for art), where craft, design and creativity (engineering), and technology play a central role (Kokko et al., 2020; Porko-Hudd et al., 2018).

To display how the science, mathematics, and craft curricula at Finnish middle schools underscore the significance of STEM knowledge in many different circumstances, the PISA Scientific Literary Framework will be used in the analysis, because it emphasizes the competences and use of knowledge in different situations in a similar way as the Finnish STEM subject-related curricula (Wang et al., 2019a). The framework offered by PISA was first released in 2007 (OECD, 2007), but was exposed to some minor revisions in 2013 (OECD, 2013). It presents how the knowledge of science and science-oriented technology are employed in different cases, for example, making careful choices. Three capabilities are highlighted by the framework: the employment of STEM (*knowledge*), and eagerness (*attitude*) to exploit this knowledge in three situations, such as (*skills*) for defining the scientific or technological problems, explicating phenomena, and producing concrete results and modeling. It also focuses on different situations and contexts in which these three capabilities are fostered. The framework presented by PISA is a book of instructions to boost scientifically cultivated individuals. That is why it foregrounds the idea that these capabilities are quite beneficial in many problem-solving situations in mature life, for they are relatable to firstly-encountered problematic cases. In addition to these, the PISA framework also recommends personal, local, and global *situations* and *contexts* in the three domains of "Science in Life and Health," "Science in Technology," and "Science in the Earth and its Environment" (Lavonen, 2021; OECD, 2007).

We have slightly modified the original PISA framework here to better analyze STEM literacy in the Finnish middle school curricula of STEM disciplines.

STEM literacy is grouped under the following areas: attitudes, knowledge, and STEM practices in line with what the National Academy of Engineering and the National Research Council have emphasized as views in STEM education (NAE & NRC, 2014). Table 1 below shows the STEM-literacy views, introduced in the Finnish middle school mathematics, biology, physics, chemistry, and craft curricula. Representative examples of the curricula are presented in Table 1.

Table 1 Goals for STEM education are analyzed in terms of aims for mathematics, biology, craft, chemistry, and physics, designated in the National Core Curriculum. The aims are interpreted based on the PISA scientific literacy competencies.

STEM-literacy views	Example of STEM-literacy views in the middle school mathematics, biology, physics, chemistry, and craft curricula in the National Core Curriculum
Attitudes	
Interest, motivation, self-concept	- *to boost students' motivation, positive self-respect, and self-reliance as students of mathematics* (Mathematics) - *to motivate students to further develop their interest in nature and its phenomena* (Biology) - *to trigger students to study physics* (Physics) - *to arouse students' interest in studying chemistry* (Chemistry) - *to make students realize how competent they are in chemistry and for further studies* (Chemistry)
Responsibility for resources and environments	- *to motivate students to participate actively in constructing a sustainable future* (Biology) - *to make students use their skills in physics to create a better future and make them question their choices about sustainable use of energy resources* (Physics) - *to make students use their skills in physics to create a better future and make them question their choices about the utilization of natural resources and life cycles of products* (Chemistry)

Table 1 (continued)

STEM-literacy views	Example of STEM-literacy views in the middle school mathematics, biology, physics, chemistry, and craft curricula in the National Core Curriculum
	to reinforce students to be economical and to make appropriate craft period decisions that promote a sustainable way of life (Craft)
Knowledge or concepts	
Use of knowledge in situations	- *to lead students to improve their reasoning and mental arithmetic skills and to motivate them to apply their arithmetic skills to different cases* (Mathematics) - *to encourage students to employ their knowledge and competences in physics in multidisciplinary learning paradigms and to provide them with some opportunities to make them familiar with the situations in which physics is applied to nature, industry, organization, or scientific circles* (Physics) - to *make students employ their knowledge and competences in chemistry in multidisciplinary learning paradigms and to provide them with opportunities to make them familiar with the situations in which chemistry is applied to nature, industry, organizations, or scientific circles* (Chemistry)
Nature of knowledge	- *to assist students in relating their knowledge about numbers to real numbers* (Mathematics) - *to help students broaden their knowledge of the calculation of percentages* (Mathematics) - *to make students observe the acclimation of organisms to different environments and to perceive the importance of different environments for biodiversity* (Biology) - *to make students learn the fundamental principles of heredity and evolution* (Biology) - *to make students realize the significance of the quality and burgeoning of scientific knowledge and methods of construction knowledge* (Chemistry) - *to lead students to learn the significance of crafts, physical skills, and technological awareness in life, society, enterprise, and business* (Craft)

Table 1 (continued)

STEM-literacy views	Example of STEM-literacy views in the middle school mathematics, biology, physics, chemistry, and craft curricula in the National Core Curriculum
STEM practices	
Predicting, explaining, and describing phenomena and using previous knowledge in design	- *to make students assess and improve their mathematical solutions and to scrutinize if their conclusions are correct or not* (Mathematics) - *to assist students in portraying the constructions and crucial functions of organisms and to comprehend the construction of biological classification* (Biology) - *to make students utilize various models to portray and explicate phenomena and to make predictions* (Physics) - *to make students employ various models to portray and explicate the structures of matter and chemical phenomena* (Chemistry).
Identifying issues, such as defining problems or asking questions and designing processes or planning investigations	- *teaching motivates students to explore and use mathematics in their own lives* (Mathematics) - *to motivate students to ask questions about the phenomena focused on and then to put the question better to carry out research and perform other activities* (Physics) - *to motivate students to ask questions about the phenomena focused on and then to put the question better to carry out research and perform other activities* (Chemistry) - *individual or community design, fabrication, and assessment of one's own or a common craft process* (Craft) - *to make students organize their work and come up with ideas, discover, and perform experiments continuously* (Craft)

Table 1 (continued)

STEM-literacy views	Example of STEM-literacy views in the middle school mathematics, biology, physics, chemistry, and craft curricula in the National Core Curriculum
Scientific interpretation of data and evidence, making an evidence-based conclusion, and evaluating working of technological applications based on observations or collected data	- *to make students improve their information management and analysis competence and to make them analyze the information from a critical perspective* (Mathematics) - *to make students transfer the knowledge about the information and communication technology into mathematics learning and problem-solving* (Mathematics) - *to make students comprehend the concept of variables and to introduce the concept of functions, and to make them create and evaluate the graph of a function* (Mathematics) - *to make students critically approach the changes in the natural environment and the influence of humans on it, and to perceive the importance of ecosystem services* (Biology) - *to inspire students to relate the abilities and knowledge in biology to their own lives, to matters on a societal level, and to the decision-making processes* (Biology) - *to direct students to work on, analyze, and display the findings of their research and to assess them critically* (Physics) - *to assist students in perceiving the working mechanisms and importance of technological applications and to motivate them to come up with ideas for basic technological problems, and also devise, develop, and transfer them in cooperation with others* (Physics) - *to direct students to work on, analyze, and display the findings of their research and to assess them critically* (Chemistry) - *to make students utilize their knowledge about the information and communication technology in learning, working on, displaying information and research findings, and to provide students with illustrative simulations* (Chemistry) - to *inspire students to exploit the ideas in the information and communication technology to arrange, manufacture, and report the craft process, and moreover, to produce and share communal information* (Craft)

The Phenomenon-based Approach to Education

STEM education aims to integrate STEM school subjects. However, there are different views and levels of integration. Choi and Pak (2006) perceived multidisciplinary teaching as the simultaneous employment of the knowledge acquired from various disciplines, but limited it to their boundaries. The interdisciplinary approach, on the other hand, pushes the limit further in that it includes interacting, blending, and linking (Klein, 2017). Moreover, interdisciplinary education is the mixture of various subject matters by establishing the links among them, which seems to be a basic approach toward the employment of STEM subjects in STEM education (Stohlmann et al., 2012).

Apart from these approaches, the transdisciplinary approaches offer the most suitable ground for the integrative restructuring of various subjects (Klein, 2006) because it takes a phenomenon or a problem such as new innovative circular economy approaches as a basis (Haatainen et al., 2021), where several disciplinary views are needed and disciplines transcend their traditional boundaries (Choi & Pak, 2006). The Finnish framework curriculum introduces this transdisciplinary approach as one approach in compulsory education (FNBE, 2014; Lähdemäki, 2018; Mård, 2021). In accordance with the curriculum, in compulsory education, each student should have at least one clear-cut long-term theme [phenomena] project or should take an interdisciplinary course that focuses on the selected theme from various viewpoints. Besides, the way in which transdisciplinary learning paradigms are organized and implemented is structured in line with the local needs and interests (FNBE, 2014). The necessity of a project is thought to yield a better learning environment, and moreover, to offer better opportunities for students to be successful in their future studies and in societal matters (Hurley, 2001). This new tendency in education also has positive influences on the teaching of STEM subjects as it offers a better foundation for transdisciplinary studies.

There will be variation between the municipalities in terms of how they implement these ideas in practice. For example, schools in the city of Helsinki have developed phenomenal learning or phenomenon-based learning in line with the integration of school subjects and the implementation of transversal competencies in school practices. The city of Helsinki recommended that schools engage with both natural and urban areas so that students can explore real-world phenomena such as energy and use of energy resources, the circular economy, and food. Based on the overall discussion, phenomenal learning is flexible and open to change (Lonka et al., 2018). It is a transdisciplinary instructional approach that is based on student inquiry and problem-solving. It is anchored learning, in which the questions raised and the topics to be learned are anchored in real-world phenomena, and the knowledge and skills are directly applied across the disciplines. Although phenomenal learning is a novel approach to teaching and learning, there are similarities between phenomenal, problem-based, project-based, and inquiry-based learning. A key difference is that phenomenal learning has a more global context and a more transdisciplinary approach than problem-based, project-based, and inquiry-based learning (Lonka et al., 2018).

Braskén et al. (2020) researched the implementation of a "new" transdisciplinary/phenomenal learning approach to compulsory education through interviewing principals and teachers and analyzing protocols from collegiate meetings. The planning of new transdisciplinary/phenomenal learning has increased teachers' collaboration in planning, implementing, and evaluating students' learning. Although there were some benefits for teachers in terms of collaboration with other teachers, the findings demonstrated that there were some difficulties in relation to the dispersedly described course objectives and the obscurity of the goals vis-à-vis the function of different subjects in the planned transdisciplinary/phenomenal learning paradigm. The study uncovered the significance of providing research-focused assistance and allocating adequate time for internalizing the process for the stakeholders to eliminate the problems encountered in the implementation process of transdisciplinary teaching.

In a quite recent study conducted by Haatainen et al. (2021), secondary school teachers' self-efficacy for integrated and/or transdisciplinary STEM education methods as a part of an in-service course was elaborated on in a more specific manner. The data were collected by a survey focusing on integrated practices and cooperative colleague collaboration after the teaching process. Despite the fact that nearly all teachers always prepared well-planned integrated activities, namely a theme day or a transdisciplinary STEM paradigm, there were a few instances where the teachers neither prepared for the course nor employed integrated techniques in STEM subject teaching, while 50% of participants did not even utilize extensive integrated teaching paradigms such as projects or courses. Instead of interdisciplinary collaboration, teachers mostly focused on collaboration within the same subject. However, the teachers focusing on integrated activities rarely or never displayed lower self-efficacy for STEM teaching. For this reason, it can be argued that the aims of the curriculum were not successfully achieved at the end of five years of application.

Eronen et al. (2019), on the other hand, investigated how eighth grade students were affected by a problem-based transdisciplinary STEM course. Using the qualitative content analysis method, data were gathered through questionnaires and interviews. It was observed that the students did not acquire much of the content knowledge offered by the course, compared with a course implementing a discipline-based approach. Yet, the students suggested that they attained some significant skills such as teamwork, problem-solving, and communicating their ideas, skills that they had never clearly associated with the teaching at school. Besides, many believed that they had gained some important skills that they would need in the future.

Emphasis on Learning of Transversal Competencies as a Part of STEM Education

In the rapidly changing and developing contemporary world, the 21st-century skills that people should have or need have been discussed (National Research Council [NRC], 2012; Wang et al., 2018). Actually, the purpose of the education that individuals receive has changed; it has become competence-centered rather than knowledge-centered (Council of the European Union, 2008). Therefore, most countries have given place to 21st-century competencies in their curricula as educational goals, especially in recent years (Reimers & Chung, 2016; Wang et al, 2019a). Finland is one of the countries which has given place to 21st-century competencies in its curricula (Lavonen, 2020; Lavonen, 2021). Vahtivuori-Hänninen et al. (2014) tried to explain through some questions why 21st-century competencies should find a place in the Finnish curriculum. These questions are: "What does education mean in the future?", "What kind of competencies should teachers and education shareholders have in order to work in cooperation and ease students' learning at the same time?", "In what type of education environments does learning occur best?", and "What kinds of competencies should students have both in their daily life and in their future life?".

In the literature, it is seen that 21st-century competencies are expressed by using different terminologies such as "transversal competencies," "generic competencies," "key competencies," and "21st-century competencies" (Reimers & Chung, 2016; Wang et al., 2018; Wang et al., 2019a). In this section, 21st-century competencies are going to be expressed as transversal competencies. Transversal competencies were defined differently in different studies. For instance, while Binkley et al. (2012) defined them as the reconstruction of education and learning outcomes' purpose in accordance with the skills individuals need in the 21st-century, transversal competencies were defined as the skills, attitudes, and values required for students' overall improvement by Care and Luo (2016). Although transversal competencies have different definitions (Wang et al., 2019a), the most commonly accepted definition is a consolidation of skills, knowledge, attitude, and values that an individual living in the 21st-century should have (NRC, 2012). According to this definition, skill is defined as the ability to use existing knowledge, where knowledge is defined as the thought which enables the individual to understand a specific topic or field, and attitude, as a concept or theory, is defined as the reaction that the individual gives to specific situations or ideas (Council of the European Union, 2019).

It can be observed when the related literature is examined that there are documents issued by different institutions such as the EU, UNESCO, and OECD which explain what kinds of transversal competencies individuals should have (Lavonen, 2020; Lavonen, 2021). Aside from the institutions which explain transversal competencies and group them, countries like Singapore, the United States of America, and Finland have defined the transversal competencies that individuals should have, and have integrated them into their curricula (Council of the European Union, 2019; Reimers & Chung, 2016; Voogt & Roblin, 2012). The main reason behind these countries defining the transversal competencies by themselves is that cultural context (Lavonen, 2020) and the economic and political situation may affect the competencies (Wang et al., 2018).

One of the earliest illustrations of transversal competencies was proposed within the scope of the "Definition and Selection of Competencies (DeSeCo)" project which was conducted under the leadership of the OECD. According to this project's definition, individuals living in the 21st-century should have competencies such as interacting with the environment efficiently, problem-solving, inquiring, creative thinking, critical thinking, and acting autonomously (Lavonen, 2021). According to the documents put forward under the DeSeCo project, transversal competencies are constituted of the four main categories of "ways of thinking," "ways of working," "tools for working," and "acting in the world." The main category of "ways of thinking" is constituted of the "critical thinking," "creative thinking," and "learning to learn" sub-categories; the main category of "ways of working" is constituted of the "inquiring," "problem-solving," and "communication and collaboration" sub-categories; the main category of "tools for working" is constituted of the "information literacy" and "technological skills, media literacy" sub-categories; and the main category of "acting in the world" is constituted of the "global and local citizenship" and "cultural awareness and social responsibility" sub-categories (Lavonen, 2021). The transversal competencies which were put forward within the scope of the DeSeCo project played an active role in defining the transversal competencies in the Finnish curriculum.

While the Finnish National Core Curriculum 2014 was being designed, transversal competencies that are expected from the individuals in the 21st-century were taken into consideration (Lavonen, 2020; Wang et el., 2018) and it has been emphasized in the Finnish curriculum since 2010 that transversal competencies should be taught in a way that can support scientific literacy (FNBE, 2014; Lavonen, 2021). In the Finnish National Core Curriculum, transversal competencies are grouped under seven categories: "competence in information and communication technology," "thinking and learning to learn," "multiliteracy," "working-life competence and entrepreneurship skills," "taking care of oneself and managing daily life," "participation, involvement and building a sustainable future," and "cultural competence, interaction, and self-expression" (FNBE, 2016), and there are efforts to integrate them into every topic and every educational level including primary school (FNBE, 2014; Vahtivuori- Hänninen et al., 2014). It is emphasized in Finland that in order for students to gain these competencies, teachers should motivate students to attend various STEM activities (Wang et al., 2019b) because STEM activities play an important role in students gaining these transversal competencies (like using knowledge in different situations, multi-dimensional thinking, critical thinking, working in cooperation, and inquiring about problem-solving) (Bybee, 2010). Aside from STEM activities, it is emphasized that project-based, cooperation-based, and phenomenon-based activities also play an important role in students gaining these transversal competencies (FNBE, 2016; Lavonen, 2020, 2021). Furthermore, in order to make students gain these transversal competencies that have been integrated into the Finnish curriculum, teachers are also required to have these transversal competencies. Thus, in 2017, with the help of a fund granted by the "Basic Education Forum," teachers were trained to teach transversal competencies to their students in their classrooms (Lavonen & Salmela-Aro, 2022; Ministry of Education and Culture [MEC], 2018).

Transversal Competencies grouped under seven categories in the Finnish National Core Curriculum are compatible with the European Union Key Competencies (Lavonen, 2021). For example; "thinking and learning to learn," one of the transversal competencies in the Finnish National Core Curriculum matches with "personal, social and learning to learn competence" from the European Union Key Competencies; "multi-literacy," one of the transversal competencies in the Finnish National Core Curriculum matches with "multilingual competence" from the European Union Key Competencies; "working-life competence and entrepreneurship," one of the transversal competences in the Finnish National Core Curriculum, matches with "entrepreneurship competence" from the European Union Key Competencies; and "competence in information and communication technology," one of the transversal competences in the Finnish National Core Curriculum, matches with "digital competence" from the European Union Key Competencies. Moreover, the transversal competencies that were defined in the OECD Future of Education and Skills 2030 competencies and the Finnish National Core Curriculum were compared (Lavonen, 2021; Vincent et al., 2019). For example; "using information independently and interacting with others for problem solving, reasoning, and concluding" and "producing inquiry-oriented and creative work," two of the competences from the Finnish National Core Curriculum, match with "practical and physical skills, that comprise inquiry orientation and problem-solving skills" in the OECD Future of Education and Skills 2030 competencies; "critically analyzing issues from different perspectives" and "finding innovative solutions that necessitate learning to see alternatives and unite perspectives," two of the competencies from the Finnish National Core Curriculum, match with "cognitive and meta-cognitive skills, which include critical thinking, creative thinking, learning-to-learn and self-regulation" in the OECD Future of Education and Skills 2030 competencies; and "learning how to take care of oneself, everyday life skills, and safety" and "developing life skills and entrepreneurship," two of the competences from the Finnish National Core Curriculum, match with "social and emotional skills, which include empathy, self-efficacy, responsibility and collaboration" in the OECD Future of Education and Skills 2030 competencies.

Despite the inclusion of transversal abilities in the Finnish curriculum, there are still difficulties with how students are going to gain these competencies via different learning activities (Korhonen & Lavonen, 2017; Lavonen, 2020; Lavonen, 2021; Saarinen et al., 2019; Wang et al., 2018; Wang et al., 2019a). It is thought that these difficulties can be overcome through different STEM applications and taking individuals into consideration with a holistic point of view.

Emphasis on Science and Engineering Careers in the Middle School Curriculum

One of the policies adopted by Finland in education, like many other countries, is to spark students' interest in learning science and in choosing professions related to science in the future (Council of the European Union, 2016; Fensham, 2009). However, it is not easy to stimulate students' interest in choosing science-related professions. Therefore, many researchers, especially science education researchers, have launched different projects and carried out various studies in order to increase students' career preferences for science (e.g., Bolte et al., 2014; DeWitt & Archer, 2015; Swarat et al., 2012).

Researchers have emphasized that the advancement of students' interest in science is extremely substantial for their STEM career choices (Dabney et al., 2012; Lent et al., 1994). Developing students' STEM career interests is quite important because many countries around the world such as Finland, Switzerland, the United States, Germany, and Austria, especially in recent years, need a bigger workforce in the area of science, technology, mathematics, and engineering (STEM) with the rapid development of technology that is impossible to keep up with (Kier et al., 2014).

In Finland, in each STEM subject there are specific aims for supporting the development of interest in STEM studies and careers. For example, the physics and chemistry curricula state that *the teaching should encourage and inspire students to study physics/chemistry, and the craft curriculum states that the teaching should emphasize students' interests*. The term "interest" in the context of curricula is used to describe the factors involved in the interaction between the student and the environment that increase or prevent purposeful actions. Interest influences what and how deeply one learns (Fredricks & McColskey, 2012; Renninger & Hidi, 2015). Researchers distinguish between individual and situational interest (Hidi & Renninger, 2006). Individual interest in a subject gradually arises and affects the students' knowledge and values, and is permanent in nature. Situational interest can arise quickly in a situation and is emotional in nature and may be short-lived (Krapp & Prenzel, 2011). The teacher can influence the development of situational interest when choosing teaching, learning practices, activities, or contexts (Bennett & Holman, 2002; Hoffman, 2002; Osborne et al., 2003). The influence of context and activity is recognized in the curricula: "*Getting to know different industries, working life, and professions, as well as job search internships, increasing students' working life awareness. At the same time, students get to know each other's areas of interest, professions, and entrepreneurship*" (student guidance); "*Teaching inspires students to discover and utilize math in their own lives*" (mathematics) and "*Conducting inquiry activities develops working and* *collaboration skills, creative and critical thinking, and inspires students to study physics*" (physics).

Recent studies dwelling on the career choices of female students related to STEM fields highlight that such factors as how much time they will devote to themselves, whether there is a communication-oriented profession, and earning a high salary are quite significant for them to choose STEM-related occupations (Kang et al., 2019). In addition to these factors, different factors in students' orientation to the fields related to STEM and choosing STEM professions have also been emphasized (Ikonen et al., 2018). For instance, in their study of ninth grade students, Ikonen et al. (2018) investigated whether parents, teachers, and friends have an effect on students' STEM career choices. Results demonstrated that almost one-third of the participants generally make their career choices individually, without listening to anyone, such as their parents, teachers, and friends. The remaining participants are of the opinion that their STEM career choices are shaped by their parents, teachers, and friends. Results also showed that there is very little discussion of STEM career choices between teachers and students in the classroom. This is an extremely disappointing result, because it is a well-known truth that such discussions between teachers and students in the classroom have a positive effect on students' STEM career choices (Bieri Buschor et al., 2014; Hazari et al., 2010).

As a part of STEM education in Finland, great importance is attached to students' engineering education, that is, their engineering career development. The main purpose of engineering education in Finland is defined as raising individuals who have a variety of knowledge and skills such as questioning, creativity, critical thinking, communication, and responsibility, which will be necessary for society and business life, and in a way that will be beneficial for people and the environment (Allt & Korhonen-Yrjänheikki, 2008; Takala & Korhonen-Yrjänheikki, 2013, 2019). This definition reveals that the engineering education given in Finland is also important for individuals to understand their own roles in society and to be aware of their own knowledge, skills, and competences (Takala & Korhonen-Yrjänheikki, 2013). Besides, the significance of sustainable development is seriously emphasized in engineering education in Finland, and various strategies and policies are being developed in this regard. However, despite all these efforts, sustainable development could not be fully integrated into engineering education in Finland (Takala & Korhonen-Yrjänheikki, 2019) because the term sustainable development has different connotations in different circles and researchers, and there are uncertainties and complexities about its definition. Therefore, it is not very easy to integrate sustainable development into the Finnish engineering education curriculum (Takala & Korhonen-Yrjänheikki, 2019).

As in other countries, engineering career development for women in Finland involves more difficulties compared to men (Naukkarinen & Bairoh, 2022; Vuorinen-Lampila, 2016). For example, in the study by Vuorinen-Lampila (2016), it was revealed that men in the first three years of engineering careers were more employed in the labor market than women with the same career background. Another study conducted by Paloheimo (2015) concluded that after graduation from engineering education, men found and were employed in better and more permanent positions than women. Another significant result of that study is that women are given fewer managerial positions in engineering careers than men. Moreover, although the different skills of women at the beginning of their engineering careers in Finland, such as communication, ethics, sustainability, and social skills, are more developed than those of men, women are more disadvantaged than men because technical aspects (entrepreneurship, creativity, etc.) are emphasized more in engineering education in Finland (Naukkarinen & Bairoh, 2022). Considering the results of the studies, the fact that engineering career development in Finland is generally more male-centered may prevent female students from engaging in engineering fields and continuing their careers in this direction.

Possibilities for Informal STEM Learning in Finland

This section discusses informal ways of STEM learning in Finland. Within this framework, entrepreneurial education, student camps, cultural events (festivals, competitions, TV series, etc.), science centers, and museums in Finland are going to be discussed and presented under specific headings.

Entrepreneurial Education in Finland

Entrepreneurship education is seen as one of the informal ways of STEM learning in Finland. Although the Finnish government has adopted a policy promoting entrepreneurship, especially with the development of technology and fierce global competition environment, it is planning to increase the number of entrepreneurs. Within this context, they are putting into action some programs and strategies that are going to enhance entrepreneurship conditions and competitive capacity (MEC, 2017a). In this context, the entrepreneurship education strategy, which was put into practice by the Ministry of Education and Culture in 2017, is accepted as one of the newest entrepreneurship strategies, and this strategy aims to enable students from different education levels to be entrepreneurial individuals and to go towards STEM fields (MEC, 2017a). Moreover, entrepreneurship strategies in Finland are supported not only by the government but also by education providers, education developers, shareholders from different levels of education, and national and local policymakers (Chiu, 2012).

There are various projects in Finland related to entrepreneurship education, for example, “Me & MyCity,” which is a simulation learning environment that aims to improve students’ creative and innovative thinking skills. There are nine local “Me & MyCity” projects in Finland (URL-8). Also, there are websites that support entrepreneurship education such as “The Economic Information Office” (URL-9) and “The Federation of Finnish Enterprises” (URL-10) alongside entrepreneurship education services such as “JA Finland” (URL-11) and “YES” (URL-12).

Student Camps in Finland

One of the informal STEM learning ways in Finland is through student camps. Basically, the camps aim to improve and strengthen the science, mathematics, and technology interests of the participants, although they also aim for the participants to know new people, get interesting information, and have fun. These camps are generally organized during summertime at LUMA centers or research centers of universities in Finland. There may be individual or team assignments or activities on these camps. Most of the camps are for students at the elementary school level (elementary school + middle school), where participants learn topics such as physics, chemistry, biology, sustainable development, environment, technology, programming, space, robotics, entrepreneurship, and coding (URL-3). For the students who are above the elementary school level, these camps are organized as courses. An example of one of these courses is “Global Challenges for Youth,” which is organized for upper secondary school students. Some camps are organized as part of research projects in Finland. Summer Science Camp, which has been organized by the University of Helsinki since 2018, is an example (URL-3).

Alongside camps that are organized face to face, virtual science camps are also organized in Finland. The content of the virtual science camps which have been organized since 2002 was developed and extended with the impact of the pandemic in 2020. Various education experts (teachers, etc.) are responsible for organizing these camps which are free of charge for students. Although most of the camps are for elementary school students, there are virtual science camps for teenagers and their families. “LUMA Centre Saimaa’s Virtual Science Club,” “University of Helsinki’s Science Education: Virtual Summer Science Camp,” and “LUMA Centre Finland: Virtual StarT Science Camps for Families and Youth” can be given as examples of some of the virtual camps (URL-3).

Cultural Events (Festivals, Competitions, TV series, etc.) in Finland

Various cultural activities such as scientific festivals, competitions, and TV series are among the informal STEM learning ways in Finland. Scientific festivals as one of the cultural activities are organized in different regions of Finland. StarT festivals are well-known among these festivals. They are organized in the summer months by regional LUMA centers in Finland. These are multifaceted festivals which aim to draw students' interest in science and technology, and every year award-winning exclusive projects and good practice examples are exhibited at these festivals. Moreover, students, teachers, and educators work in cooperation during the festivals. These festivals are normally conducted face to face but in 2020, because of the pandemic, it was organized online as "Virtual StarT" (URL-3). Another kind of cultural activity is scientific competitions. One of the projects named "Data Star" in English and "Datatähti" in Finnish can be given as an example of these competitions. This is a two-stage programming competition for middle school students in Finland (URL-13). Another example of these competitions is "Tämä toimii-Liikkuva lelu" also named "This is a working-moving toy" in English. Based on recycling, the aim of this project, which is organized every year in Finland, is to make students design a moving toy in a creative way without buying any material and by using the materials that are present at schools and the materials that are defined (URL-14). Apart from these competitions, the "StarT Competition" (URL-15), "The Amazing Race of Science" (URL-3), and "The Traditional Chemistry, Math and Information Technology Competition" (URL-3) are among the competitions which contribute to informal STEM learning in Finland. Although they are not as common as scientific festivals and competitions, some national TV series are among the cultural activities that contribute to informal STEM learning in Finland. One of these TV series is named "Robomestarit" in Finnish and "Champions in Robotics" in English; students conducting competitions in Robotics are portrayed in this series (URL-16).

Science Centers in Finland

Science centers are one of the informal STEM learning places in Finland. The best known of these science centers is “Heureka.” Heureka offers entertaining, exploratory, and pleasant learning experiences for visitors of all ages in the science, mathematics, and technology fields (URL-17). Another science center is “Arktinen Keskus.” This science center handles environmental and social problems in order to raise awareness of the societies on topics such as sustainable development, biodiversity, and environmental protection (URL-18). Some centers are named both science centers and museums in Finland. One example of these science centers is “Lusto.” Lusto, named “Suomen metsämuseo ve metsätietokeskus” in Finnish, is a center that emphasizes the importance of forests in Finnish culture and focuses on the interaction between people and forests in Finland; it appeals to visitors of all ages (URL-19).

Museums in Finland

Museums are among the other informal STEM learning places in Finland. For example, The Museum of Technology is the only one for general technology in Finland, but these museums representatively portray how Finland was able to develop from an agrarian society to become a country developing high technology and producing innovation (URL-20). Another example of the museums in Finland is the internationally accepted Design Museum (URL-21). Besides, there are museums within universities. The Zoology museum on the campus of the University of Helsinki, the University of Jyvaskyla Science Museum, and The Natural History Museum of Central Finland are examples of these museums (URL-3). Apart from these museums, The Helsinki University Museum and The Finnish Museum of Natural History are among the museums providing informal STEM learning opportunities in Finland (URL-3).

Trends and Issues in STEM Education in Finland

In our analysis we have recognized five trends in STEM education in Finland. We summarize these trends next. We then present five issues which are challenging and not supportive of STEM education practices.

Trends

1. Implementing a national core curriculum emphasizing STEM competences

The definition of STEM education or literacy varies in curriculum documents and research papers (Boğar, 2021). However, we have followed in this chapter the definition of the National Academy of Engineering and the National Research Council (NAE & NRC, 2014). In line with their definition, the Finnish National Core Curriculum emphasizes competences in STEM subjects. The competences are similar to the competences outlined in the PISA framework. Second, the STEM curricula emphasize sensemaking of real-world, rigorous, relevant phenomena. In line with this second characteristic, the curricula emphasize inquiry or project-based learning as a pedagogical approach. The third characteristic is the emphasis on learning of transversal competences as a part of STEM education. The fourth characteristic of STEM education in Finnish education is the emphasis on science and engineering careers as a part of STEM education.

2. Applying the phenomenon-based approach to STEM education

The Finnish framework curriculum introduces a general transdisciplinary approach (FNBE, 2014). According to this idea, each student should have at least one clear-cut long-term theme [phenomena] project or should take an interdisciplinary course that focuses on the selected theme from various viewpoints. Besides, the way in which transdisciplinary learning paradigms are organized and implemented is structured in line with local needs and interests. This new approach has had positive influences on the teaching of STEM subjects as it offers a better basis for transdisciplinary studies (Lähdemäki, 2018; Mård, 2021). In addition to STEM education at school, there are several possibilities for informal STEM learning in museums, university labs, and clubs.

3. Emphasizing learning of transversal competencies as a part of STEM education

While the Finnish National Core Curriculum was designed during the years 2012 -2013, several transversal competencies models were analyzed (Vahtivuori- Hänninen et al., 2014) in order to ensure an appropriate definition of transversal competencies in the Finnish context. In the Finnish National Core Curriculum, transversal competencies are grouped under seven categories as described above (FNBE, 2016) and they should be integrated into every discipline. STEM subjects have an important role in students gaining these transversal competencies (like using knowledge in different situations, multidimensional thinking, critical thinking, working in cooperation, and inquiring about problem-solving) (Bybee, 2010). Aside from STEM activities, it is emphasized that project-based, cooperation-based, and phenomenon-based activities also have an important role in students gaining these transversal competencies (Lavonen, 2020; Lavonen, 2021).

4. Emphasizing science and engineering careers in middle school curricula

In Finland, each STEM subject has specific aims for supporting the development of interest in STEM studies and careers. For example, the physics and chemistry curricula state that the teaching should encourage and inspire students to study physics/chemistry. Craft teaching should emphasize students' interests. The term “interest” in the context of curricula is used to describe the factors involved in the interaction between the student and the environment that increase or prevent purposeful actions, here orientation to STEM careers.

5. Strengthening networks to support STEM education

In a decentralized education system there is no heavy guidance or control by the state or government. Therefore, various voluntary networks aim to improve students' and teachers' knowledge and skills related to STEM fields. The most prominent of these networks in Finland is "LUMA Centre Finland." This network has two major aims. The first is to improve both the lifelong learning and research-based teaching of the teachers working at different education levels. The second aim is to both motivate students at different levels in science, mathematics, and technology learning (URL-6). Another important network in Finland is "The Innokas Network." This is known as a teacher network in the most general sense and aims to help teachers gain STEM competences (URL-7).

Issues

1. Teacher education tradition emphasizes discipline-oriented teaching

Lower and upper secondary teachers are trained at traditional universities in five-year master-level programs in Finland. The master's degree includes studies in two subjects, such as physics and mathematics or chemistry and mathematics. These teachers do no or very limited study in engineering, such as coding and robotics. Therefore, secondary teachers have strong identity in teaching their major and minor subjects and do not necessarily think at all about integrated STEM education. This heavy orientation towards two subjects is the most challenging issue from the point of view of STEM education.

2. Discipline-based curricula emphasize teaching of STEM subjects as separate subjects

Lower and upper secondary curricula have a long history of being built as subject-specific curricula. All aims, descriptions of core ideas or content, descriptions of most appropriate teaching and learning methods, and guidelines for assessment and allocation of lesson hours are very disciplinary oriented. It does not help that the curricula do not emphasize integration of school subjects.

3. Curriculum materials emphasize disciplinary-oriented teaching

It is known that curriculum materials or textbooks guide STEM-teachers in their lesson planning. Especially in a country where there is not heavy control and testing, other issues than the curriculum easily guide or orient teachers in their planning processes. The textbooks for Finnish lower and upper secondary education are discipline oriented.

4. Interdisciplinary collaboration among teachers is insufficient

The teacher's salary in Finland is mainly based on the weekly lesson hours in a classroom. Therefore, teachers feel strongly that their salary comes from the planning of lessons, teaching, supervision, and assessment. There have been no incentives for interdisciplinary collaboration and co-planning of interdisciplinary and transdisciplinary learning. However, during the last five-year period, 100 hours per year has been allocated for teacher collaboration and co-planning. This is one step towards interdisciplinary collaboration.

5. Second and third cycles of education emphasize disciplinary orientation

Finnish upper secondary education and higher education are disciplinary oriented. This means that middle school teachers have a mindset that they have to prepare students for these disciplinary-oriented secondary and higher education studies.

However, there are promising examples of multi or transdisciplinary approaches in higher education. With the establishment of Aalto University in 2010, the initial and most significant reconstruction of higher education institutions occurred (Chiu, 2012). Moreover, they reconstructed programs and added several multidisciplinary elements and STEM elements to the programs. Aalto University has been designed to be the world's prominent "innovation university" so that researchers and students in different fields such as economics, art, technology, and design can work in interdisciplinary cooperation (Chiu, 2012). In general, there has been a positive welcome of this combination. In 2016, higher education institutions underwent another, more complicated reform when it was decided that the University of Tampere and Tampere University of Technology should be combined. The most recent network, FI-Tech Turku, was established through combining science, mathematics, and engineering into a single unit (MEC, 2017b). Although the experiences of these three STEM-oriented higher education collaborations have been positive, no further steps have been taken.

Conclusion

This chapter delineates how STEM-oriented aims are recognized in the Finnish middle school STEM subjects or mathematics, biology, chemistry, physics, and craft science curricula, although the Finnish middle school curriculum does not explicitly address STEM education. Each of the STEM subject's curricula implicitly incorporate competencies that relate to STEM education, as shown in Table 1. First, the integration of knowledge across science, technology, engineering, and mathematics domains is incorporated into the Finnish biology, chemistry, physics, and craft curricula in multiple dimensions, such as life and health, the Earth and the environment, and technology. The mathematics curriculum includes links to many subjects, not only STEM subjects. In addition to the integration of STEM disciplines and student engagement in real-world science and technology related problems or challenges, the following STEM characteristics are recognized in the Finnish middle school curricula: STEM literacy; transversal competencies; STEM workforce readiness, and connections of STEM to society including working life, interest, and engagement. However, it must be noted that the analysis of STEM orientation in the Finnish middle school curriculum is challenging because there are various definitions of STEM education.

STEM education characteristics are revealed in the Finnish curricula in three significant ways. First, science and engineering process skills introduced in the curricula require the concretion of science with mathematics, engineering, and technology. For example, the chemistry curriculum recommends guiding students to perceive the applications of chemistry in technology. The curriculum also encourages students to participate in generating ideas for solutions that require the use of chemistry knowledge, and to design, develop, and apply those ideas. Second, the subject-specific curriculum emphasizes the student's engagement in science inquiry and technology-related problems.

Third, the middle school curriculum emphasizes the learning of transversal competencies and recommends that learning them could be realized by involving students in project-based, phenomena-based, and multidisciplinary studies (Vasquez et al., 2013). The implementation of study periods, which concentrate on topics of particular relevance to students, is in line with the definition of STEM education as well.

All science subjects emphasize the importance of becoming familiar with science, technology, and engineering related occupations, careers, and industries. Moreover, specific school counsellor teachers introduce students to working life and career possibilities, including STEM career possibilities. They also organize periods when students are learning in working life conditions.

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Status and Trends of STEM Education in Germany

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Abstract

This chapter shows the strengths and weaknesses of the German education system in relation to STEM education. It reveals a massive gap between supply and demand of the STEM workforce, even if Germany seems to be in a good position in terms of international comparison. Furthermore, the education system is described at ISCED levels 0 to 8 in the general and vocational fields and its outcome is evaluated. This chapter points out that the 16 federal states of Germany dominate when it comes to decisions in the education system and that the central government lacks direct control. Even though there are some policies of central relevance, the educational landscape in Germany is therefore very heterogeneous. It is shown that there are many different STEM education initiatives and that most of them rely on distribution from partners that are not part of the public education system. On the other hand, there is much less dynamic evolution within the established, STEM-related school subjects. It may be an unexpected recognition that Germany lacks the STEM-relevant subjects of technology and computer science. Additionally, there is no uniform, established didactic concept for integrated STEM education. Thus, STEM is still taught as separate subjects. This chapter points out some relevant trends and issues of STEM education and concludes that the German STEM education strategy has worked sufficiently to date but may not be a sufficient solution in the future, because it accepts that integrated STEM education is a mandatory offering that may mainly emphasize the affinity of young people who are already interested in STEM.

Keywords: extracurricular STEM education, separated STEM education, STEM education in Germany

Introduction

Nowadays life takes place in a highly technological environment that shapes the individual as well as the society. Technology is so omnipresent in our modern industrial society, in people's private and professional lives, that in a certain sense it is no longer perceived for what it is: an “artificially” produced result of human creativity, triggered by individual or social needs and committed to satisfying them. It is providing for our daily life in nearly all areas. Even self-evident things such as clothes, buildings, and roads are products of human thinking and creating. Without all of these innovations human life would be prehistoric like in the stone age. However, technology has been developed further and nowadays digital improved technologies like robotics and artificial intelligence are at the cutting edge. The development and production of modern technology needs competent people as well as elaborated use of technology. Developing and promoting these competences is the aim of STEM education all over the world. These four letters are known to be the first letters of the meta-disciplines of science, technology, engineering, and mathematics. Science can be understood as a combination of traditional subjects like physics, chemistry, or biology, but even more specific subjects like biochemistry, medicine, or astronomy can be assigned to science. Technology can also include various technical disciplines like electronics, manufacturing techniques, information technology, or construction technology. Engineering can stand for various engineering disciplines on the one hand, but on the other hand it includes methods to plan, design, construct, build, and analyze solutions. Mathematics is a traditional discipline that supplies important methods by logical thinking, calculating and proof finding to all other disciplines. To participate in our modern, technology-infused world, all these four meta-disciplines are relevant. None of them could be removed without jeopardizing the idea of STEM. Some claim that STEM should even be expanded to include the meta-discipline of arts.

In Germany, the term “STEM” is not in common use, but there is a counterpart to STEM called “MINT.” These four letters stand for mathematics, informatics (Computer Science with a focus on coding), science, and technology. German research and reports refer to this term in general, and even though it may not be the same in school contexts due to different school subjects, STEM and MINT are often used synonymously. Outside of school contexts, MINT is not necessarily associated with traditional school subjects. It can refer to a broad range of subject groups in the fields of natural sciences, mathematics and statistics, computer science, communications technology, engineering, manufacturing, and construction.

Supply, Demand, and the Supply-demand-gap of the STEM-skilled Workforce

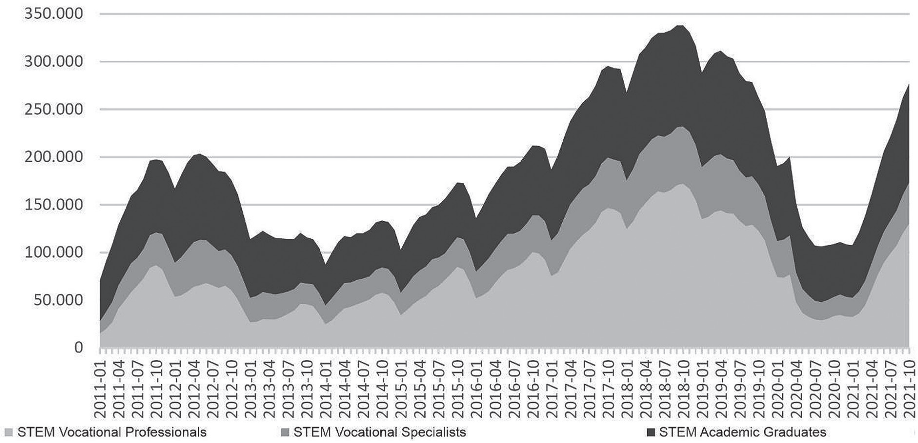
To deliver a description of the supply of the STEM-skilled workforce, some statistics about education graduations are relevant. The OECD found that in Germany, upper secondary level students graduated at the age of 18-19 from general education programs in 2019 (OECD, 2021). These graduates leave the general education system and potentially head for tertiary education programs to gain a further qualification (vocational education or university studies). They are not yet available for the labor market. In vocational programs, students graduate at an average age of 19-22. This group of persons is qualified to work as professionals or to participate in further education programs. According to a 2020 OECD study (OECD, 2020), the vocational education system in Germany ensures a high level of employability. Around half (46%) of students in upper secondary education in Germany opt for a vocational education program. The majority (89%) of all students in vocational education programs participate in a combined school-based and in-company training program (Dual System), which demonstrates the dominant role of dual vocational training in Germany. Only 3% of people with vocational qualifications are unemployed, compared with twice the OECD average.

Basic vocational education and training significantly improves the chances of lasting employment. In 2019, 88% of 25-34 year-olds in Germany with a vocational qualification (at upper secondary or post-secondary non-tertiary level) were in employment. This corresponds to the proportion of employed people of the same age with a university, technical college, or other tertiary degree, which is also 88%. In all OECD countries, employment rates rise the longer it takes to graduate. In Germany, a good 86% of adult upper secondary graduates between the ages of 15 and 34 find a job within the first 2 years after graduation. The OECD average is 66%. This employment rate in Germany even remains at that relatively high level 2 to 5 years after graduation. However, the share of NEETs (not in education, employment or training) in Germany in the 18-24 age group increased from 8.2% in 2019 to 9.4% in 2020, but these figures are below the OECD average of 14.4% in 2019 and 16.1%. in 2020 (OECD, 2021). In 2017, per capita spending per education participant in Germany was higher than in most other countries ($13,529 each compared to the OECD average of $11,231). On the other hand, according to the 2020 OECD report, Germany just spent 4.2% of gross domestic product (GDP) on education, which is below the OECD average of 4.9%.

The 2019 OECD report revealed that in no other OECD country is a STEM degree as popular as in Germany (OECD, 2019). More than one third of all graduates (36%) obtained a tertiary degree, that is, a university degree or a career-oriented tertiary education degree, in a STEM subject (OECD average: 24%). Germany seems be in a good position according to its STEM-skilled workforce compared to most other countries. Nevertheless, an analysis of the Federal Employment Agency in 2019 revealed that the situation gives no cause for satisfaction (Bundesagentur für Arbeit, 2019) as the vacancy time for filling registered jobs has tended to increase in recent years. At 129 days, the vacancies for STEM workers were open for an above-average length of time (the average in 2018 was 115 days), and the trends show a worsening of the situation. In the longer-term view compared to 2008, the increase in the vacancy time for STEM workers is even stronger at 46 days. Nevertheless, there was no general shortage of skilled workers for STEM occupations detected in 2018 overall, but there were already bottlenecks in individual occupational fields, for example in software development, programming, and energy technology.

The German Economic Institute (Institut der Deutschen Wirtschaft [IW]) recently published more worrying forecasts as follows (Anger, et al., 2021). In October 2021, there was a total of approximately 460,900 vacancies in STEM occupations. At the same time, 186,984 people nationwide who would like to work in a STEM occupation were registered as unemployed. From this it can be deduced that nationwide at least 273,900 vacancies in STEM occupations could not be filled across all requirement levels. Considering the qualification mismatch, the labor shortage across all STEM occupational categories in October 2021 amounts to 276,900 persons. This corresponds to an increase of 155% compared to October 2020, bearing in mind that the Coronavirus pandemic had a major impact on the labor market at that time. Comparing instead with the monthly gap of October 2019 (i.e., before the pandemic), it reveals that the value is even higher than before the pandemic (October 2019: 263,000). Figure 1 indicates that the trend of rising STEM occupation gap before the pandemic seems to be continuing into the future.

Figure 1 STEM professional gap



Source: Anger et al., 2021, p. 5.

The latest available figures quantify the gap for STEM workers in February 2022 at 286,800 persons – 137.4% more than in February 2021. Labor demand in STEM occupations has increased by around 131,000 jobs (equivalent to 37.8%) compared to February 2021. In February 2022, there were around 477,600 STEM vacancies to be filled (Plünnecke & Anger, 2022). If the gap is differentiated according to STEM fields, the greatest bottleneck can be seen in the energy/electrical occupations with 81,300, in the machine/vehicle technology occupations with 49,000, in the IT occupations with 46,400, in metalworking occupations with 40,700, and in construction occupations with 37,900 (in October 2021).

In the coming years, more than 62,200 STEM graduates will leave the labor market each year for reasons of age (Anger et al., 2021). In 5 years, the annual demographic replacement demand will increase by 6,600 to 68,800. In the case of STEM graduates, around two-thirds of graduates will be needed solely to meet replacement needs and will thus not be available for further growth in employment. For STEM professionals, the current demographic replacement demand is around 270,800 and will increase by about 20,400 to 291,200 in 5 years. The annual new supply of professionally qualified STEM workers will be significantly lower than the demographic replacement demand in the coming years. Overall, the annual demographic replacement demand will thus increase by 27,000 in 5 years.

The high importance of digitalization is evident in employment in IT occupations and will lead to an increase in demand for IT specialists and will further exacerbate the situation of the STEM labor market. While the employment in STEM occupations rose by 2.2% from the end of 2012 to the end of the first quarter of 2021, the number of IT specialists increased by 51.9%. In the specialist occupations (master craftsman/ technicians), the increases for the STEM occupations as a whole were also lower (11.7%) than those of the IT specialists at 17.5%. Among the academic occupations, the increase in IT expert occupations was 96.9%, which was significantly higher than for STEM experts overall (+ 37.5%). The Federal Agency for Employment just released statistics that show an increase in new STEM employment of 65,000 in February 2022 compared to 2021 (Bundesagentur für Arbeit, 2022).

In the view of the companies, IT experts will be of particular importance for the development of climate-friendly technologies and products in the next 5 years, which will also have a strong impact on the demand for STEM professionals. In terms of all companies, around 32% expect the demand for IT experts to develop climate-friendly technologies and products to increase in the next 5 years. Other STEM experts and other professionals will also be increasingly needed: 19% expect the need for engineers or environmental engineers to increase. Companies with 250 or more employees are particularly relevant for employment. Of these companies, 63.2% expect an increasing demand for IT experts, 43.1% expect an increasing demand for engineers/environmental engineers, 32% for other STEM experts, and 43.3% of other specialists for the development of climate-friendly technologies and products.

Educational System in Germany

The Federal Republic of Germany consists of 16 federal states, including the three city states of Berlin, Bremen, and Hamburg. In general, the specific design of school policies is not the responsibility of the federal education ministry, but of the 16 states. These all have their own education ministries that operate independently of each other. That causes the peculiarity that each state has a specific education system when it comes to specific school subjects or curricula. Even the school types can be different in some cases, especially at the lower secondary level. An important authority at the national level in this context is the "Standing Conference of the Ministers of Education and Cultural Affairs" (Ständige Kultusministerkonferenz [KMK]). The KMK has released some regulations about the structure of the education system in Germany that are obligatory for all states (Kultusministerkonferenz, 2021). Accordingly, the 16 education systems are comparable and can be described as one system, even though there are some minor differences that will be explained in this section.

The internationally used eight (nine with pre-school education) ISCED levels are divided into five main education levels in the German education system: Elementary, primary, lower secondary, upper secondary, and tertiary education. The system provides a high degree of permeability - the transition to the next level is often possible in several ways and with different educational pathways.

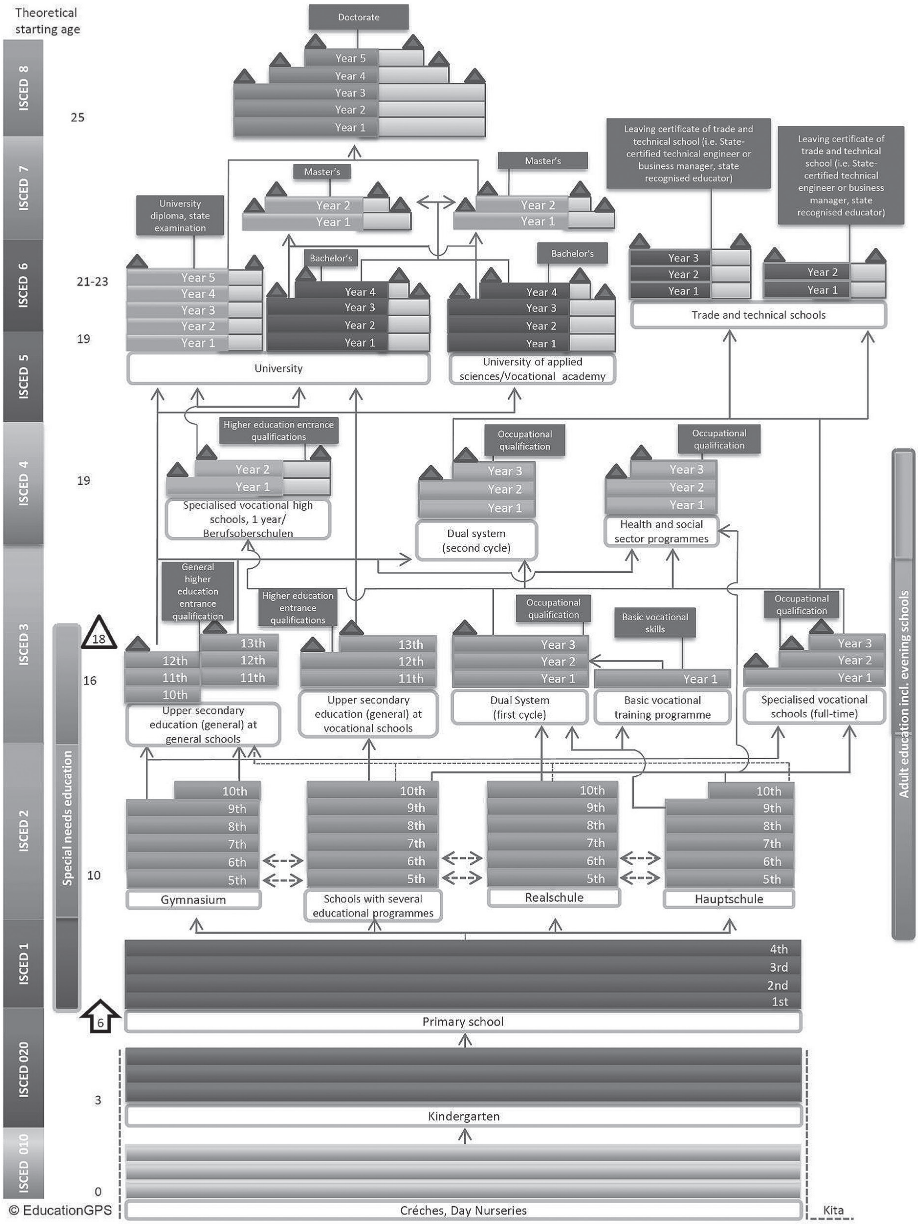
The German state has an educational obligation. Therefore, there is a legal requirement to attend school for at least 9 or 10 years. During this time, a lower secondary school leaving certificate is normally obtained. Every course of education at public schools can be completed free of charge. In some cases, however, the costs of educational materials must be borne by the students themselves. Relatively low fees may be charged at tertiary and elementary level universities. Trade and technical schools leading to a qualification at

ISCED level 6 on a part-time basis must be paid for by the student. Under certain circumstances, however, state subsidies are possible.

The majority of general education schools are public; only 14% are privately run (in 2019) and the trend is positive. The propensity to attend public school correlates with parental income. While only 3.6% of low-income households attended a private school in 2016, this share was 18.7% among millionaire income earners (Grossarth-Maticek et al., 2020). Private schools must be accredited by the state; parents are not allowed to teach their children themselves.

The OECD has created the following overview of the German education system that shows all these pathways and its "educational stations":

Figure 2 The German education system



Source: EducationGPS, 2020.

Elementary education (ISCED 0)

The elementary sector provides services for children up to primary school age (usually 6 years). This includes, for example, crèches, kindergartens and pre-school classes. These programs are not covered by compulsory education and are therefore voluntary, but in high demand. The need for elementary service units has been rising for a number of years. In 2019, 785 new child daycare facilities were built in Germany and the number has increased to 52,870 (Autorengruppe Bildungsberichterstattung, 2020). It is no more just a matter of childcare during the parents' working hours. For a fairly long time now, day-care centers have been seen as educational institutions.

Primary education (ISCED 1)

The Primary school is the first type of school that children obligatorily attend. It usually covers four grades, in some federal states even six. At the end of primary school, a recommendation for secondary school is made on the basis of the children's performance. But ultimately, it is the parents who decide. Germany follows the approach of inclusion consistently in most of the federal states. This means that disadvantaged children also attend mainstream schools in heterogeneous learning groups. Where this is not reasonably possible, a special school can be attended.

Lower secondary education (ISCED 2)

The lower secondary level comprises educational programs that lead to the "first school-leaving certificate" (9 years) or the "intermediate school-leaving certificate" (10 years) after grade 9 or 10, or students prepare for a higher qualification. The titles of the qualifications vary in the federal states, as do the types of school that offer these programs. There are schools that offer one of the two qualifications (Hauptschule and Realschule) as well as schools that offer two or three programs (including the option of the upper school-leaving certificate, Abitur). In some federal states there are integrated comprehensive schools where pupils can choose between different levels of difficulty of subjects. In all states there is the school type, Gymnasium, where lower secondary school-leaving qualifications are acquired on the way to the Abitur.

Upper secondary education (ISCED 3)

At upper secondary level, students attend full-time vocational or general education schools. The general higher education entrance qualification (Abitur) can be obtained after 12th or 13th grade at the Gymnasium or another type of general education school with an upper level. However, there are also vocational schools that provide an upper level and lead to the Abitur after 13 years.

Besides the Abitur, occupational qualifications can be obtained at ISCED 3 with the German Vocational Education System, that is divided into three sectors. There is, as in most European countries, a school-based sector in which specialized vocational schools offer and fully implement training courses. Anyhow, more popular in Germany is vocational training with a combination of in-company and school-based learning (dual system). The third sector of vocational education and training is the transition system, which supports enrolment in one of the above-mentioned educational programs if required.

Dual system

This sector is called “dual” because the training takes place in two places of learning: in the company and in the vocational school. Almost 47% of all persons over 15 years of age in Germany had acquired their highest vocational qualification in the dual system in 2019. A further proportion followed vocational training with upgrading training or higher education studies (Maier, 2021a). This means that more than every second adult has completed vocational training in the dual system, so it is of particular importance in Germany. In particular, STEM professionals are often educated in this sector (Bundesagentur für Arbeit, 2019).

Basic vocational education program

This so-called “transition system” is still quite young in relation to the other sectors of vocational education and training. It was first defined in the National Education Report in 2006. It includes all educational offers "that are below a qualified vocational training and do not lead to an official training qualification, but aim at improving the individual competences of young people to take up training or employment or also enable them to catch up on a general school leaving qualification" (Konsortium Bildungsberichterstattung, 2006).

This sector includes training programs lasting up to one year that are aimed at youths and young adults making the transition from school to work. The aim is to improve their chances of finding an in-company or school-based option for education. No formal qualification is acquired. In particular, training courses leading to a higher school leaving certificate are not included in this sector. This sector is very heterogeneous and has many specific variants spread across Germany. Some of them can be credited to training periods in the dual system, others support young people with learning difficulties to get ready for further education programs.

In 2019, 26.3% of the entries (417,648 persons) in the vocational training system were to be attributed to the “transition system” sector. The trend is currently downwards. However, the figures of recent years show that events of major significance (such as political conflicts or economic crises) lead to an increased demand for offers in this sector (Maier, 2021b).

Specialized educational schools (full time)

In this school-based vocational system, training occupations are learned exclusively at Specialized Educational Schools. These are legally recognized vocational training programs that are carried out without a company connection. The main difference from vocational education and training in the dual system is the place of learning. Training takes place exclusively at the school, although practical phases in the form of company placements are also provided for a large number of training occupations in the school-based vocational system.

The school-based training programs, like those in the dual system, end with final examinations that assess vocational competence for the respective occupation. The number of apprenticeships in these schools has risen steadily over the past decades, and now more than 200,000 students choose such an apprenticeship every year. More than 80% start in the field of social and health service occupations. STEM professions have a small share, as they are preferably learned in the dual system (Schultheis et al., 2021).

Post-secondary non-tertiary education (ISCED 4)

Programs of this level provide further education based on an upper secondary (general or vocational) qualification and can be acquired at different types of schools depending on the specific state. They focus on special subject areas (e.g., the health or social sectors) or in professions of the dual system that require an upper secondary school leaving certificate as an entry requirement. Some special vocational high schools like the "Berufsoberschule" provide programs to get an entrance qualification for higher educational programs at tertiary level.

Short term tertiary education (ISCED 5)

There are no standardized programs at this qualification level, although there may be some singular programs in some states for special contexts.

Bachelor's or equivalent level education (ISCED 6)

Many different study programs can be acquired at Germany's universities, universities of applied sciences and vocational academies (trade and technical schools). In 2018, approximately 300,000 students graduated at this level

(Autorengruppe Bildungsberichterstattung, 2020). Besides the internationally known Bachelor's degree, there are also some national-specific degrees like state examinations or diplomas, even though most of the studies have been reformed and internationally standardized within the Bologna Process. Vocational academies provide programs that lead to a bachelor's equivalent degree in specific areas of profession without studying at a university (e.g., Technician, Master Craftsman). Many of these vocational programs take place part-time at an evening school.

Master's or equivalent level (ISCED 7)

The Master's degree is generally the second higher education degree and is usually obtained at a university. However, there are also universities of applied sciences that offer Master's programs.

Doctoral or equivalent level (ISCED 8)

Traditionally, doctoral degrees are provided by universities in Germany. Since the Bologna Process, some states have enabled even universities of applied sciences to host doctoral programs.

Germany's central government has a limited influence on the education system due to the fact that the responsibility to regulate the specific education policies is given to the 16 federal states. As a consequence, there are many different regulations, policies, and practices in all specific areas of school education. For instance, schools in Germany will have different school subjects with even different subject-specific and subject-didactical approaches. Mathematics and sciences such as physics, chemistry, or biology have long been established school subjects in Germany. Informatics, Computer Science, or even Technology are not that established and cannot be taught at any location, depending on the state's regulations.

Any school has the right and the duty to define specific courses in most grades depending on the specific states' regulations. The teaching offerings of the schools sometimes depend on local impacts like the proximity to neighboring countries (language courses), local traditions, demand of students, supposed attractiveness, and the professional expertise and personal inclinations of the school's teaching staff. In addition, any school can set up its individual curriculum for the subjects and the grades. As a consequence, the specific learning content will vary from one school to another. That makes comparisons of teaching content and learning outcome between schools very difficult, even if they are located in the same city.

To sum up, the competence to exert an influence on school education is distributed to Germany's government, the federal states' governments, and the schools. Just a few policies on quite an abstract level (school system in general) 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 themselves (subject conference and school management). One more indirect but important influence is up to municipalities and cities that provide the schools by financing them and setting up the school's infrastructure (for instance buildings and room equipment).

The Status of STEM Education

As already described above, the German education system is very heterogenous. As a consequence, the status of STEM education is also very different depending on the local conditions. In this section, the author focusses on aspects that will have a general, supra-regional impact.

Contexts of STEM Education

In 1997 the KMK decided to assess the outcomes of the learning processes of Germany's schools. As a consequence, Germany participated in the PISA assessment. The results were not satisfactory and caused the so called "PISA-shock" in Germany. The established concept, which until then had been primarily oriented towards input control, proved to be uncompetitive internationally. Therefore, the KMK resolved to evaluate the outcome of the general school education at regular intervals. Furthermore, the KMK initiated the development of output-oriented education standards, what was no less than a paradigm shift in Germany. Furthermore, the additional PISA-E assessment (comparison of learning outcome between the federal states) revealed that the performance level of pupils varied greatly between the federal states in Germany. With that in mind, the education standards should contribute to educational equity.

These standards specify the competencies students must possess to achieve accredited educational goals. They ensure the comparability of school-leaving qualifications acquired in different types of schools across Germany. They therefore refer to qualifications in school subjects and do not specify the specific educational content in the different grades. The decision of how, when, and what is to be learned in each grade is still up to the states and their schools. The standards focus on core areas of a specific subject. They do not cover the entire range of a learning area, but formulate subject-specific and cross-subject basic qualifications that are of importance for further schooling and vocational training by enabling transferable learning. The functional task of educational standards (output-oriented) and the goals of contemporary general education (input-oriented) do not contradict, but rather complement each other. Within the totality of efforts to ensure and increase the quality of school work, educational standards represent a central link to realize the comparability of school-leaving qualifications acquired in different types of schools (Kultusministerkonferenz, 2005). However, in addition to the function of verifying learning outcomes, the standards also have a developmental function. They should serve as an orientation and a benchmark for the further development of the school system (Kultusministerkonferenz, 2010). To provide scientific support for quality development in education in the federal states of Germany, the Institute for Quality Development in Education (Institut für Qualitätsentwicklung im Bildungswesen [IQB]) was founded at the Humboldt University in Berlin. Since then, it has made a significant contribution to the standardization and review of educational standards, and regularly publishes educational reports. For instance, the IQB was commissioned to develop empirically validated competency level models. All educational standards are competence-oriented and based on these level models. Thus, they allow a standardized assessment of student performance.

Standards have not been developed for every single school subject, but exclusively for subjects that are taught at all schools all over Germany. To date, the KMK has released the following education standards:

- For the primary level (grade 4) for the subjects German and mathematics,
- for the lower secondary school leaving certificate (grade 9) for the subjects German, mathematics, and first foreign language (English/French),
- for the intermediate school leaving certificate (grade 10) for the subjects German, mathematics, first foreign language (English/French), biology, chemistry, and physics,
- for the upper school leaving certificate for the subjects German, mathematics, and the continued foreign language (English/French) as well as for the natural science subjects (biology, chemistry, and physics).

As already mentioned, the German equivalent to STEM is MINT. In both, mathematics and sciences are included. Table 1 provides an overview of the available educational Standards with direct STEM-relevance:

Table 1 Available educational standards with STEM-relevance

	Mathematics	Sciences	Technology, Engineering, Informatics
Primary level	Yes	No	No
Lower secondary	Yes	No	No
Intermediate secondary level	Yes	Yes (Biology, Chemistry, Physics)	No
Upper secondary school	Yes	Yes (Biology, Chemistry, Physics)	No

It is obvious that there is a focus on traditional subjects like mathematics, biology, chemistry, and physics. Because mathematics is the only listed subject that is taught in every school in Germany, it is also the only subject with standards for every qualification level. Sciences are not to be taught in explicit subjects in primary schools. At the lower secondary level this may vary between the states and local schools. What is also noticeable is that there are no standards for the disciplines of technology, engineering, or informatics (computer science) at all, because there are no uniform subjects at general education schools like this in Germany. However, in some federal states there are subjects like "technology" or "informatics" and there are also integrated subjects that have affinities to these subjects, but the KMK does not provide national standards. Due to that, these subjects will not become a part of an official national or international education monitoring.

To address this shortage, the Association of German Engineers (Verein Deutscher Ingenieure [VDI]) has developed education standards for technology education for the intermediate level, which can be taken by any school as a national standard (Verein Deutscher Ingenieure [VDI], 2007). The Association for Informatics (Gesellschaft für Informatik [GI]) has also developed standards for informatics education for the primary, intermediate secondary, and upper secondary levels (Gesellschaft für Informatik [GI], 2008, 2016, 2019).

The GI additionally just released an informatics education monitoring report. It claims that in two states no informatics education takes place at all, in eight states informatics is just available as a voluntary class, and in six states informatics is an obligatory subject (GI, 2022).

In 2004 the KMK released a framework for education in children daycare institutions. This framework distributes the early education in several education fields, including the field "mathematics, nature science and (information-) technology." Like all the education fields, it is for guidance only and has a recommendatory character, not an obligatory commitment. The frame only gives a brief outline of the content. In this way, interest is to be piqued and basic knowledge in dealing with mathematics and technical devices is to be provided (Kultusministerkonferenz, 2004).

Germany's vocational education system is more complex compared to the general education system. Due to that, there are many policies issued by different authorities at the federal and state levels. Education in the dual system is regulated by the National Vocational Education Act (Berufsbildungsgesetz [BBiG]) and the German Craft Code (Handwerksordnung [HwO]). For each recognized apprenticeship profession there are two important standards. For the school learning part at the national level, the KMK releases framework curricula that define learning fields. The federal states must take these frameworks as a basis for their own detailed curricula for vocational schools. The in-company part is standardized by the National Vocational Training Ordinance (Ausbildungsverordnung). Vocational full-time school education at specialized vocational schools is regulated by the states exclusively. For health and social sector education the KMK has developed some standards. For further professional education programs there are currently 220 ordinances at the national level and not less than 746 ordinances and regulations at the state level (Bundesinstitut für Berufsbildung, 2021).

In many countries, the promotion of STEM education disciplines has become a priority (OECD, 2017). But even though there is a high demand for STEM graduates in the labor market, STEM subjects continue to be attractive to only a small share of education participants. On average across OECD countries, only 16% of tertiary entrants (all ISCED levels) enroll in engineering, manufacturing technologies, and construction, which represent the disciplines with the largest percentages (OECD, 2019).

The OECD certifies Germany's top position in STEM education in an international comparison. According to the 2018 OECD report, Germany has the highest rate of first-year students in STEM subjects (OECD, 2018). The number of first-year students in the first semester in the subject group mathematics, science, and engineering has almost doubled in the past 10 years. In 2016, 24% of tertiary graduates in OECD countries obtained a degree in STEM subjects on average, while in Germany 36% obtained a university degree or a vocationally oriented tertiary education degree in a STEM subject (OECD, 2018). Women's interest in doctoral studies, including in STEM subjects, has increased. Almost one in two new doctoral students (46%) in Germany is female, and around 37% of new students opt for a doctorate in a STEM subject. The OECD average is 31% (OECD, 2021).

In upper secondary classes, boys dominate in physics or technology. Only 25% of girls take physics as an advanced course, only 11% of young women take up a STEM vocational education, and only 25% of female students start an engineering degree, although engineering takes the highest share of STEM studies (Acatech & Körber-Stiftung, 2021). In 2020, 2,944,145 people studied at a German university (or university for applied sciences) with a women's share of 49.9%; and 1,101,943 students (37%) took a STEM subject with a woman's quota of 31.7%. The share of students at a university for applied sciences was 43% in 2019, while 57% studied at a university (Autorengruppe Bildungsberichterstattung, 2020).

Despite all efforts to strengthen the STEM education approach, the "MINT

Nachwuchsbarometer 2020" concluded that the STEM young talent situation in Germany has not changed for the better in recent years. Students are less and less interested in mathematics and science subjects, and the performance of 15-year-olds is also declining. The same study also stated that for 20% of 15-year-olds, successful transfer to qualified vocational training is thus at risk due to their weak STEM skills. Looking at the situation at universities, one can conclude that in an international comparison, Germany has an above-average number of young people starting STEM studies, and the proportion of women is increasing slightly. However, the high number of dropouts continues to be a challenge (Acatech & Körber-Stiftung, 2020).

Germany's STEM Education System

STEM education became a fixed and self-evident part of the German educational landscape in a short time – there is no question about that. Many STEM programs and initiatives appeared in the last 2 decades. It is therefore very surprising that the search for general and uniform goals of STEM education does not lead to any clear results. There do not seem to be fixed key objectives for STEM education in Germany.

STEM, or the German equivalent MINT, is not a school subject with one subject-specific science as a background and concept-providing reference. It does not have as long a tradition in school as an established subject like history or arts. Measured against the persistence of school subject concepts, STEM is still a new phenomenon without any school tradition in Germany. It has not been introduced as a holistic concept, but as a pragmatic reaction to the recognized lack of a STEM workforce in the labor market. Due to this, there are some very pragmatic goals of STEM education in Germany. Of course, the supply of the economy with STEM workforce is one, and maybe even the main attitude of STEM education. Its absence of disciplinary tradition may be seen as a serious deficiency, but it can also be understood as an advantage. STEM can be very open-minded, flexible, and modern. Due to that, it can easily include new aspects of education. With this in mind, some further objectives of STEM education can be postulated. Such a goal is the integration of school-external learning occasions. It includes real-life locations such as companies, museums, universities, makerspaces, nature, public places, public institutions, and many more. To take real-life problems into account without the restrictions of curricular settings is another, attractive aim. This way, the connections between the single STEM / MINT subjects may come to the fore. An important intention of STEM education is certainly a practice-oriented learning style. This implies a problem-orientated way of working that addresses real-life problems and situations.

Although modern human life is heavily influenced by technology and informatics, these two disciplines are not implemented at all in many schools in Germany. Introducing such subjects across the board would be a lengthy project. It could therefore also be an implicit and highly unofficial concern of STEM education to implement these disciplines into the German education system quickly and without time-consuming bureaucratic and controversial political processes. Explicit goals, on the other hand, are the promotion of talented pupils in the STEM field and the fostering of interests in STEM topics, also against the background of career choices. There is no doubt that digital education is a central challenge for the German education system. A connection between digital education and STEM education is often articulated (Kultusministerkonferenz, 2017). In this respect, the promotion of digital competences could also be a goal of STEM education. STEM education takes place at any education level – from elementary to tertiary level. Therefore, STEM education also becomes a linking function of education stages.

Next to more or less pragmatically motivated intentions of STEM education, there are at least two goals on a normative level. STEM sometimes still has a negative image in the meaning that only “computer nerds” or “logic-freaks” can have fun with STEM topics. The promotion of a positive STEM image is an official goal (BMBF, 2019). Especially girls and young women should become more interested in STEM-relevant activities. Another official task for STEM education is a more traditional aim of school education: It should develop competencies and literacy in the wide field of STEM (BMBF, 2019).

Emphasizing STEM Education at the Institutional Level

To describe if and how STEM is fostered in educational institutions from elementary childhood education to upper secondary classes, the composition of STEM education must be mentioned first. In one understanding of STEM there would be education classes that do not differentiate the single subjects of STEM (or MINT in Germany). In this understanding, the individual disciplines merge into a holistic concept. Depending on the learning context, the appropriate subject aspects are selected and applied as needed. As already mentioned, this integral concept is no traditional school subject in Germany. Education standards are not available and integrated STEM education is difficult to implement into regular classes, because no lesson time can be allocated for this. Due to that, integrated STEM education can most often be offered outside the compulsory lessons as voluntary classes.

The other concept of STEM education provides a separation into the individual STEM-relevant subjects. In Germany, these are mathematics, the science subjects of physics, chemistry, and biology, and at some schools also computer science and technical education. There are educational standards and curricula for mathematics and the natural sciences in all federal states (but not for type of school). Informatics (computer science) is not implemented in all federal states and neither is technical education. Moreover, technical education does not always occur as a separate school subject, if at all, but as an integral part of subject combinations such as economics-work-technology. A central problem is the lack of coordination between the individual subjects. However, this would be necessary in order to link the independent subject lessons with each other. A similar concept existed before the German reunification in the former GDR. However, the school system at that time was very centralized and the state could exert direct influence on every single lesson, so it cannot be easily adapted to today's situation (Hüttner, & Tönnsen, 2015).

A detailed overview of the implemented STEM educational elements would have to list every single federal state. The following Table 2 lists the ISCED level and attempts to provide an overview of how the average situation all over Germany is.

Table 2 STEM education according to ISCED levels 1 to 3

ISCED level	Separated STEM education	Integrated STEM education
Level 0: elementary education	-	Phenomena-based learning Elementary learning projects Projects with external partners
Level 1: primary education	Separated into the subject of mathematics As a separate topic within an integrated subject with focuses on social science and natural science	Integrated within an integrated subject with focuses on social science and natural science
Level 2: lower secondary education	Separated into the subjects of mathematics, physics, chemistry, and biology (share depends on federal state and local circumstances)	Voluntary classes and learning projects (often in the afternoon or on holidays, even with external cooperation) In a few federal states within integrated subjects like "Sciences and Technology"
Level 3: upper secondary education	Separated into the subjects of mathematics, physics, chemistry, and biology (share depends on federal state and local circumstances)	Voluntary classes and learning projects (often in the afternoon or on holidays, even with external cooperation) In a few federal states within integrated subjects like "Sciences and Technology"

Many schools in Germany are trying to increase their attractiveness by raising their profiles. There are numerous ways to do this. For example, schools enter into cooperation with external educational partners or participate in educational programs. If local conditions allow, schools can set subject priorities and offer more courses in specific subject areas like languages, arts, culture, or STEM-related topics. Such profile-raising offerings can also be recognized by regional, state, or federal institutions and are designated by certificates. However, there are numerous certificates with very different requirements and from many different institutions, so there is no systematic overview of certified schools for Germany available.

In 2019, 11% of general education schools and 25% of vocational schools in Germany were privately operated (Grossarth-Maticek et al., 2020). Public schools often claim that they can promote the individual talents and gifts of their students much better than state schools. This is usually justified by smaller learning groups, and better equipment and learning infrastructure. On the other hand, education at private schools is not free of charge and can lead to high costs, so it can be questioned to what extent it is primarily the monetary or the intellectual elite that is being promoted here. Regardless of this question, private schools potentially provide good support for individual talents. Among them, there are also schools that offer explicit support in the STEM area. In general, the education in STEM subjects is relatively resource-intensive compared to many other subjects due to the need for specific and expensive infrastructure and equipment. Private institutions often seem to avoid this financial effort, as they have to calculate their teaching offerings also considering monetary aspects. Due to that, expensive STEM education mostly takes place at public universities; the contribution of private universities to the training of the highly demanded professionals in STEM fields is small. Only 11% of new enrolments at private universities are in STEM subjects, compared to 41% at public universities (Autorengruppe Bildungsberichterstattung, 2020).

In addition, in some federal states there are sporadic state schools specifically for highly gifted pupils. These schools specialize in the phenomenon of giftedness, which can be manifested in completely different subject areas, including STEM-relevant subjects.

In the vocational school sector, on the other hand, there are many schools that focus explicitly on STEM topics. This is because these schools often specialize in vocational fields. For example, there are vocational schools for business, social work, health care, administration and also technology. In technical vocational schools, various ordinarily technical subjects and courses are offered, but all other STEM subjects also play an important role here.

General education schools offer a wide range of courses. Natural sciences and mathematics are compulsory subjects nationwide, which can also be taken as an advanced course in upper secondary school, depending on regional circumstances. But there may also be elective courses on STEM subjects in lower secondary education. There are also numerous educational programs and initiatives in the STEM field at regional and supra-regional levels that general education schools can take advantage of. Often this is carried out in optional courses within the framework of compulsory lessons or as an extra-curricular offer. In this way, interested pupils can also be supported in the STEM area.

Fostering STEM Education at the National Level

In Germany, there are many initiatives in the STEM education area at the local level, including programs of the federal states. The main idea is to bring the stakeholders (students, teachers, companies, research institutes, universities, museums, associations) together and foster their activities. At the national level, STEM-related programs may be supported by the Federal Ministry of Education (BMBF). At the executive level, foundations become an important role. A small selection of some initiatives is briefly described as follows.

In 2019, the BMBF presented a central action plan for STEM (BMBF, 2019).

It intends to promote STEM skills in four areas: STEM education for children and young people, STEM professionals, opportunities for girls and women in STEM, and STEM in society. A key element is the promotion of regional STEM clusters. The aim is to strengthen STEM education across the board through extracurricular offerings for children and young people.

The BMBF, together with partners from science, industry, social partners, media, associations and others, launched one more central initiative to attract significantly more young women to future careers in STEM fields. Many programs and initiatives have been funded as part of this “STEM pact.” This includes, for example, the “Komm, mach MINT” (Let’s do STEM) initiative. It informs and inspires girls and young women about STEM courses of study and professions by presenting a realistic picture of engineering, scientific professions, and opportunities for women in these fields.

One of the best-known school competitions is “Jugend forscht” (Youth Research). Its aim is to get young people from the 4th grade up to the age of 21 interested in mathematics, computer science, natural sciences, and technology. In this way, it is expected that talents can be found and promoted. Every year, about 120 competitions are held throughout Germany within this framework. Participation in the competition is voluntary and there are attractive prizes to be won.

The foundation “Haus der kleinen Forscher” (House of Little Scientists) is committed to early education in the STEM field in daycare centers and primary schools throughout Germany. In this way, it wants to make children strong for the future and enable them to act sustainably. The essential core of this educational initiative is an extensive training program for educational specialists and teachers. In this program, educators learn how to provide inquiry-based learning and how to engage in the learning process together with the children (co-construction). The foundation is very successful with this concept. In 2021, 50% of all daycare centers participated in its training offers.

Educational Olympiads are held around the world in STEM subjects such as mathematics, chemistry, and physics. Like the Sports Olympics, the aim is to compete with others and become the champion in a discipline. The BMBF supports the staging of the Olympiads at the national level. Anyhow, in the end, the Olympics in Germany are run by a foundation.

The “Informatik-Biber” (Computer Science Beaver) is Germany's largest student competition in the field of computer science. Over 400,000 students took part in the most recent competition. The competition is aimed at children and young people in grades 3 to 13 from all types of schools. Participation is even possible without any prior knowledge of computer science.

The “MINT-EC” initiative is explicitly dedicated to the promotion of STEM talents. It is a national excellence network for schools with upper secondary level and a distinctive mathematics, science, and technology school profile. The aim of this initiative, which was launched by the KMK, foundations, and business associations, is to develop committed schools into STEM talent incubators. The network develops teaching materials, provides digital offers and infrastructure, and organizes competitions and excursions. Currently, 339 grammar schools (Gymnasium) and schools with classes at the upper secondary level belong to the MINT-EC network.

STEM Education Assessments in Germany

Measuring the success of STEM education and all the STEM initiatives is difficult in Germany due to the various responsibilities for education. Anyhow, the “Insititut für Qualitätsentwicklung im Bildungswesen (IQB)” (Institute for Quality Development in Education) regularly conducts a nationwide survey of achievement levels in specific areas (IQB Education Trend). Most recently, mathematical and scientific competencies at the lower secondary level were examined in 2018 (Stanat et al., 2019). More recent results are not yet available due to the Coronavirus pandemic. In mathematics, nearly 45%

of all ninth-graders in Germany met or exceeded the KMK standard for the intermediate school leaving certificate in 2018. Around 24% of students failed to meet the minimum standard in mathematics. More than half of ninth graders met or exceeded the KMK standards for the MSA in the competency area subject knowledge in the established natural science subjects; the quotas were 71% (biology), 56% (chemistry), and 69% (physics). In the competence area knowledge acquisition, these rates are 60% (biology), 64% (chemistry) and almost 77% (physics). The minimum standard for the MSA was not met in these two areas of competence by 5% and 8% (biology), 17% and 11% (chemistry), and 9% and 6% (physics) of the students. In 2016, the IQB's recent evaluation of primary schools took place (Stanat et al., 2017). Among others, the mathematical competencies of fourth-graders were measured. KMK regulatory standards were met or exceeded by 62% of students. However, 13% did not succeed and just 15% reached the maximum standard. Both surveys allowed a comparison of the federal states. The results for primary and lower secondary education were comparable, but the scores varied significantly between the states. In both studies, students in Bavaria and Saxony achieved well above average performance, while the city states of Berlin and Bremen were both clearly below average. It is suspected that the cause may be in the different state-specific configurations of the education system.

At the international level, the latest Programme for International Student Assessment (PISA) from 2018 revealed that German 15-year-old students had significantly better competencies in Mathematics (500 points, competence level III) than the OECD average (489 points). However, more than one-fifth of 15-year-olds have only rudimentary mathematical skills, which can lead to problems participating in society. About 13% of young people reached the highest competence levels, V and VI, which is significantly above average. However, this proportion is declining. Germany's students also scored above the OECD average (489 points) in science, with 503 points. However, one fifth of young people did not reach proficiency level II. This proportion has risen compared with 2015, particularly among boys (Reiss et al., 2019).

The recent Trends in International Mathematics and Science Study (TIMSS 2019) pointed out that Germany is above the international average in the area of mathematical competencies for fourth graders. Anyhow, compared exclusively to the participating EU and OECD countries, the performance of students from Germany is slightly below average. Nevertheless, the proportion of primary pupils who were able to develop only rudimentary or low mathematical competencies (levels I and II), is at around a quarter. In addition, only 6% of students were able to achieve level V, which is a low rate by international standards. A comparison over time shows that the proportion of students achieving only levels I and II increased slightly in TIMSS 2019. This drop in performance is evident across all three content areas surveyed (Schwippert et al., 2020).

STEM Teacher Education in Germany

Regardless of the type of school, in general, teachers have to hold a Master's degree of ISCED-level 7 before they can be employed at a public school. General education teacher studies include two or three subjects and pedagogy studies. Vocational teachers take one general education subject and one vocational subject. In their first 2 years in school they complete a traineeship. In Germany, there are specific studies and Master's degrees for teachers where they may study teacher exclusive courses or shared courses with non-teacher students. Besides this regular way, academics from suitable subjects have the option of lateral entry into the teaching profession. In some vocational schools, professionals with a ISCED-level 6 certificate teach practical subjects, for instance in handicraft or workshop classes. After completion of their teacher education, teachers get lifetime employment quite fast, depending on the demanded and the studied subjects. After that, participation in continuing education in parallel with the teaching activity is voluntary. However, further education courses may be required to hold coordinating or leadership positions in schools.

Reforms of STEM Education in Germany

From time to time, some adjustments are made to the German education system by reforming some policies. The system in general is quite static and changes need a considerable amount of time. Quicker innovations at the national level seem to be difficult because the states have to agree and reach a consensus. Currently, there are many activities at the national level to foster digitalization in education. There is a national "digitalization pact" and initiatives to enrich the teacher education and to update the school infrastructure. Some states have even reacted in recent years and strengthened subjects like computer science or integrated subjects like "science and technology."

Trends and Issues in STEM Education

Trends

In recent years, STEM education has developed strongly. A number of trends have emerged that are likely to have an impact in the future.

1. STEM education is involving partners from outside schools

STEM activities take place everywhere and every day in the real world outside of schools. STEM is relevant in our daily life as well as in professional contexts in companies. Public spaces like museums or maker spaces offer STEM activities that people can join in their spare time. In addition, the government is funding many STEM initiatives. To sum up, there has been a dynamic evolution of STEM in educational contexts and various possibilities for formal and informal STEM education in Germany has occurred in the last decade. The German education system, on the other hand, is a rather ponderous construct. It cannot keep up with the rapid development of STEM on its own, either on a material or on a personnel level. For this reason, it relies on opening up to external educational opportunities and incorporating motivated professionals and initiatives into its own curriculum. This consistent opening is a novelty and will certainly be a feature of innovative STEM education in the future.

2. Promotion of women in STEM education is a key

Traditionally, boys and men have been more represented in STEM fields than girls and women. This is already unsatisfactory from an equality perspective. In view of the current and expected shortage of skilled workers, the advancement of women is also of economic importance. Germany can no longer afford to do without the creativity and workforce of women in STEM fields. Therefore, various initiatives for attracting women to STEM topics and professions have been raised in the past. These efforts will also be an integral part of STEM education in the future.

3. Digitization is increasingly included in STEM education

In the German equivalent of STEM (MINT), informatics /computer science is an obvious component. At the same time, Germany lacks comprehensive computer science education. Even though individual federal states have introduced the subject of computer science, it cannot be assumed that digital education is systematically taught in any school in Germany. Moreover, computer science proper does not cover the broad spectrum of digitization. Aspects such as automated manufacturing, robotics, social impacts, and much more are only included in a basic digital education that goes beyond pure computer science. STEM education, because of its openness and flexibility, offers numerous opportunities to experience digitization in real-world use cases. Furthermore, it can be observed that the possibilities offered by digital technologies are used in the sense of a useful tool for STEM education. This way, digitalization becomes learning content as well as a learning tool in STEM education.

4. Clustering and arranging of individual offerings for school education

The number of educational offerings in the STEM field has grown steadily, resulting in a confusing conglomeration. In order to facilitate systematic STEM education in schools and in out-of-school contexts, work is currently being done on structuring the educational offerings. For example, regional STEM clusters are being established. Since the many individual offerings are constantly changing and evolving, structures will also have to be reformed and updated in the future so that suitable educational opportunities can be found as needed.

5. Vocational education makes a major contribution to STEM education

The central pillars of the German education system are general and vocational schools. While STEM education in general education schools has to compete with numerous other disciplines for hourly quotas, vocational education programs are more specialized. While vocational schools also contribute to general education at varying degrees, they are often focused on occupational fields, making it possible to set priorities. Thus, vocational fields related to STEM potentially provide more intensive STEM education than general education schools. This is of particular benefit to technical education, which in many German states is not included in general education, or only to a limited extent.

Issues

The OECD attests that Germany has very good figures when it comes to interest in STEM (OECD, 2019). This could easily give the impression that the German STEM education strategy does not have any problems. However, there are a number of issues:

1. The government is losing control of the teaching activities

The involvement of many external partners makes STEM education modern and flexible, but it can also be seen as a disadvantage. The German state has an education and training mandate, for which it ultimately collects tax money. This is accompanied by the legitimate requirement that the state can vouch for the quality of the educational offer. However, when independent people take over the task of teachers at the executive level, this can be criticized. What is taught in the classes is not directly influenced by the responsible ministries and even not by the teachers anymore. It might be asked if the learning content is still under the control of educated (and paid) teachers or if others decide what is to be learned and how. The education system has become strongly dependent on externals. But what happens if the partners are no longer willing to take on a significant part of German's STEM education?

2. STEM education is determined by local available partners

In Germany there is the principle of educational equity. This means that everybody has the same possibilities for education, no matter their location. In fact, the quantity of STEM education offerings varies greatly depending on the region. In 2019, a foundation released a report about the distribution of STEM hubs in Germany (Körber-Stiftung, 2019). These hubs work as regional network nodes to coordinate STEM education offerings and demands. The report revealed that there are federal states with high availability of STEM offerings (Nordrhein-Westfalen: 381,000 residents per hub) while other states have very low availability (Schleswig-Holstein: 2,911,000 residents per hub). However, it must be considered that there may be additional STEM education offerings of unconnected players besides the hubs that are not recognized by this report. Anyway, it is obvious that the offerings correlate with the economic power of the region.

3. The concept of separated S.T.E.M. is dominating in German schools

As already mentioned, the German education system is oriented quite traditionally. There are national education standards in most general education schools for the subjects of chemistry, biology, physics, and mathematics. These standards define the subject in isolation from others. The federal states have to follow these standards and teach these subjects separately, too. For establishing an integrated STEM-subject, the KMK would have to develop new standards. However, standards will just be developed for subjects which exist in all states of Germany. Due to that, visionary standards that could be an impulse for a new, integrated STEM subject all over Germany can probably never be released by the KMK.

4. The regular education system lacks technology education

As described in the introduction, technology is an essential part of daily life and therefore must be an obligatory part of general education. In addition to that, technology is an integral part of the German equivalent to STEM ('MINT'; T = technology). Even if Germany would give up the idea of integrated STEM education, it would not be able to provide comprehensive and nationwide technology education because many states have not yet introduced a technology subject. This is absolutely inexplicable, especially for a leading industrialized country such as Germany. At the same time, the discipline of engineering and technology has great potential to provide a long overdue didactical structure for STEM education.

5. Germany's teachers lack integrated STEM competence

Integrated STEM education means not to think and teach in separate STEM subjects exclusively. To overcome this tradition, teachers who are competent in all STEM disciplines are needed. However, the classical teacher education system is not able to educate such multidisciplinary teachers. Teacher education is limited to two, sometimes three, subjects studied in isolation from each other. An integrated STEM subject does not exist in Germany, so teachers cannot prepare for it. In addition to subject-specific training, there is also a lack of didactic concepts for integrated STEM education. Although there are research activities in this area, there is currently no established STEM didactics.

6. The infrastructure of Germany's schools is inadequate

As separated as the individual STEM subjects are in Germany, so are the subject rooms. In many schools, there are separate rooms for chemistry, physics, and biology, each equipped exclusively for the corresponding subject. Computer science, on the other hand, often takes place in rooms with stationary computers, if at all. In many schools, there are no technology classes. If there are, they often take place in student workshops that are geared toward manual material processing. For an integrated STEM education, there is a lack of flexible and interdisciplinary rooms and appropriate equipment.

Conclusion

At first glance, the German STEM education system seems to work well. By international comparison, there is a great deal of young STEM talent and the shortage of skilled workers is moderate (OECD, 2019). The government supports numerous STEM education projects and the range of STEM education offerings has grown steadily in recent years (BMBF, 2019). The vocational education system is efficient and well-integrated with the general education system. It provides an important contribution to STEM education and ensures a high employability rate (Bundesagentur für Arbeit, 2019).

It only becomes apparent at second glance that the German education system also has essential problems with regard to STEM education output. The development of the shortage of skilled workers in STEM professions is cause for concern, as the gap between vacancies and job seekers is widening (Anger et al., 2021). A deeper look into the German education system also reveals some problems related to the STEM education system. The detailed conditions for school education are determined by each federal state. Therefore, there is actually not “the” German education system, but a German education system with 16 variants. Within these variations, there are additionally many local factors that determine the specific implementation of instruction in public educational institutions. Thus, the state has no possibility to directly influence specific teaching. As a result, even regular subjects for which there are nationwide standards vary across the states and are comparable only in terms of outcomes (school-leaving qualifications). The KMK educational standards, which are authoritative in Germany, bring with them a difficulty of their own: Since they are adopted only for subjects that are established nationwide, they are not a suitable instrument for fundamental innovations such as the introduction of new subjects. In order to make immediate adjustments to the very sluggish education system, the government therefore only has the option of promoting programs parallel to the established school subjects. This has been done increasingly in recent years and has led to a diverse range of educational offerings for STEM subjects, which is fundamentally a positive development. Parts of these offerings can be integrated into the STEM subjects that have traditionally been taught separately. However, there is the problem that content which is an integral part of STEM cannot be included in the traditional subject catalogue. Content areas such as engineering, technology, or informatics / computer science education explicitly addressed in the German counterpart to STEM (‘MINT’) have no place in the established subjects in many German states.

To upgrade the current strategy of separately taught STEM subjects (S.T.E.M.) for more complete STEM education, at least the subjects of technology and computer science would have to be introduced in all federal states. So far, this is only the case in some federal states. In reality, however, STEM rarely occurs as the singular result of a single discipline. Mostly, technical products and applications of private and professional everyday life are the result of an interaction of several STEM disciplines. In order to make them accessible for learning purposes, an integrative, cross-disciplinary perspective is therefore needed. This is difficult to realize with the German education system, since integrated STEM education has no uniform, subject-specific basis at universities, in teacher training or in didactics. At least there are initiatives in didactic research for the development of STEM subject didactics, which could serve as a basis for integrative STEM education. To date, STEM education has mainly taken place outside the traditional classroom as a voluntary afternoon activity or an optional class. Numerous STEM educational offers can also be taken outside of school in students' spare time. To sum up, the current integrated STEM education in Germany is characterized by a central attribute: It is mostly voluntary. This can be seen as a positive feature that determines the success of German STEM education. On the other hand, it can be interpreted as a flaw, because it implies that many young people will not get in touch with integrated STEM education if they were not already interested in STEM topics before.

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Status and Trends of STEM Education in Hong Kong Special Administrative Region

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Abstract

STEM education was introduced into the Hong Kong curriculum with the goal of nurturing local innovation and technology talent. The positioning of STEM as a key feature in the continuous curriculum change in the two STEM policy documents (CDC, 2015, 2016) gives it a non-subject status and a partial-curriculum framework, so that teachers have to refer to the curricula of the Science, Technology, and Mathematics Education Key Learning Areas for content and assessment information. The stated purpose and vision of the STEM curriculum change renders its implementation by teachers and schools challenging in terms of the building of a shared vision, the change capacity of organizations and individuals (e.g., Fullan 1993, 2001), teachers' readiness, among others. Adopting the categories in Moye et al. (2020) together with consideration of the local context, 5 trends and 6 issues are identified and discussed in this chapter. They cover topics including the nature of the STEM education curriculum change and policy-related matters and funding, roles of authentic hands-on problem solving as a core learning experience, implementation of the integrative STEM curriculum, the influence of popular iconic STEM items (e.g., AI, coding, VR, etc.), and teacher professional development.

Keywords: STEM, STEMaker, design & technology, technology education

Introduction

Supply, Demand, and the Supply-demand-gap of the STEM-skilled Workforce

The concern about enhancing the Innovation and Technology (I&T) sector to contribute to Hong Kong's economic development has all along been conferred a high priority in the policy agenda. In her latest Policy Address 2021(HKSARG, 2021), the Chief Executive of the Hong Kong Special Administrative Region (HKSAR) Government announced the policies and measures to develop an I&T ecosystem[1] to "enable re-industrialisation to take root in Hong Kong and complement I&T development in Shenzhen and the GBA [The Great Bay Area]"[2] (HKSARG, 2021). In achieving this policy imperative, and among other measures[3], it is clear that the nurturing of local talent, especially among the younger generation, shall play a crucial role in its success.

Although effort and funding have been invested, Hong Kong has been struggling hard to cultivate a critical mass of talent among the younger generation. It has long failed to attain top ranking (ranked 20 out of 63) in terms of investment in and development of home-grown talent[4] (Legco, 2020). According to Census and Statistics Department (2019) figures, there were only 6.6 research-

1 Other goals are to enhance Hong Kong's roles of International Centres in finance, Transportation, Trade, Legal and Dispute Resolution Services and Aviation.

2 As promulgated in the 14th Five-Year Plan [of the Central Government of the People's Republic of China]

3 Including "[providing] Land / Infrastructure for I&T" and "Industrial Estates," "Promoting Research and Development," "[continuing the inputs in] Technology Investments," and "Involvement in National Research and Development Work" (HKSARG, 2021)

4 As revealed in the International Institute for Management Development's 2019 World Talent Ranking (Quoted in Legco, 2020)

ers[5] per thousand employed people in 2018 in the territory. When compared to the figures of many developed economies and Organisation for Economic Co-operation and Development (OECD) countries[6], this ratio is barely capable of sustaining an innovative and intelligence-intensive economy.

The need to enhance Hong Kong's capacity to nurture local I&T talent raises the necessity to look for novel educational initiatives like STEM in primary and secondary education.

5 The actual 2018 figure is 33,577 and the 2020 figure is 36,106.

6 For example, Denmark = 15.7/1000, South Korea, 15.3/ 1000, Sweden = 14.8/1000, Finland = 14.5, Taiwan 13.5/1000, Japan = 9.8/1000. Data sources: Census and Statistics Department (2019) and Organisation for Economic Development and Co-operation (2020). (Quoted in LegCo, 2020)

Table 1 The structure of the schooling system in Hong Kong[7]

Stage (Age Group)	Local Schools: Government schools, Aided Schools & private / DSS[8] schools	Degree Programs	Sub-degree Programs	Vocational Education	International Schools
Post-graduate Level		Coursework and Research PG programs		Career pathways	
	undergraduate qualification				
18+	Post-Secondary (4 years)	Degree program by 22 local degree-awarding institutions	Top-up degree (2 years) Sub-Degree (2 Years)	self-financing higher diploma programs by post-secondary education institutions Pre-employment and in-service vocational and professional education and training programs by the Vocational Training Council	
	Hong Kong Diploma of Secondary Education				purported to meet the demand for school places from overseas families living, working, or investing in Hong Kong
Key Stage 3- 4 (12-18)	Secondary (6 years)				
Key Stage 1- 2 (6-12)	Primary Education (6 years)				
K (3-6)	Kindergartens (3 years)				

7 https://www.studyinhongkong.edu.hk/en/hong-kong-education/education-system.php and https://www.gov.hk/tc/about/abouthk/factsheets/docs/education.pdf are referred to in preparing this part of the report. [Accessed March 2022]

8 Schools under the Direct Subsidy Scheme (DSS) "…are allowed to have greater flexibility in various areas including resources deployment, curriculum design and student admission, …. may collect school fees for the provision of additional support services and school facilities." (https://www.edb.gov.hk/en/edu-system/primary-secondary/applicable-to-primary-secondary/direct-subsidy-scheme/info-sch.html) [Accessed March 2022]

The Influence the Hong Kong Government Exerts on STEM Education

The HKSAR Government plays a dominant role in the development of STEM education in schools in Hong Kong through the enactment of policy and the appropriation of funding, resources, and support.

In two consecutive Policy Addresses, the Chief Executive of Hong Kong made STEM a measure to equip future generations for the keen global competition ahead (GHKSAR, 2015, para. 152, 2016, para. 89). With that in mind, the Education Bureau (EDB) published the consultation document "Promotion of STEM Education, Unleashing Potential in Innovation—Overview" (hereafter Overview; CDC, 2015) and later the "Report on STEM Education-Unleashing Potential in Innovation" (hereafter Report; CDC, 2016).

Therefore it is the intent of the Government to promote and start STEM early in primary and secondary schools to narrow the aforementioned talent gap[9].

The Status of STEM Education

Contexts of K-12 STEM Education

Policies and strategy

The two policy documents (CDC 2015, 2016) announce the positioning of STEM education in Hong Kong. "**Promotion** of STEM education is intro-

9 "[b]asic STEM concepts are best learned at an early age – in elementary and secondary school – because they are the essential prerequisites to career technical training, to advanced college-level and graduate study, and to increasing one's technical skills in the workplace" (CDC, 2016, p. v, quoted in LegCo, 2020)

duced as a key emphasis under the ongoing renewal of the school curriculum (also known as Learning to Learn 2.0) …" (CDC, 2015, p. 2; CDC, 2016, Preamble; emphasis added). It is posited as an educational change (Fullan 1993) in the school curriculum, that is, it is neither a subject nor a curriculum in its own right.

In order to undertake a holistic examination of the Hong Kong school curriculum, the EDB set up the "Task Force On Review Of School Curriculum" (Task Force) in 2017 to gather intelligence from stakeholders so as to develop directional recommendations to optimize the curriculum. As a key element of the curriculum change, naturally STEM education falls under the scrutiny of the Task Force. The Task Force launched a 3-month public consultation from which the feedback and comments are summarized and directional recommendations are proposed in the "Optimise the curriculum for the future: foster whole-person development and diverse talent: Final Report" (Task Force, 2020). The final report was submitted to the government for consideration and formulation of policy actions.

It is generally agreed that the Task Force precisely identified certain key aspects of STEM education implementation that had not been sufficiently addressed in the endeavors since 2016. These include, most importantly, a "designated committee" at policy level to steer and supervise the implementation of the change. In the meantime, some recommendations are in place (e.g., STEM coordinators have been appointed, PDPs (Professional Development Programs) are being rolled out) and the education community is expecting the central guidelines to be stipulated in the "…**Handbook** to promote STEM education under the principle of STEM for ALL" (Task Force ,2020, p. 33; emphasis added) as committed to by the EDB[10].

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10 Press release "EDB accepts directional recommendations of Task Force on Review of School Curriculum" in Para. 6 "Laying the groundwork for developing a STEM Handbook, which features good examples of school-based STEM education to clarify the expectations

Research and development findings which guide current and future STEM practices

Around the time that STEM education was mentioned in the Policy Address (HKSARG, 2015), there were surveys and studies carried out by the EDB, NGOs, education professional bodies and universities[11] to probe the contexts that will influence the about-to-emerge STEM movement and to contemplate the interaction of factors and stakeholders in view of generating initiatives and recommendations to facilitate its development. It is observable that these studies are predominantly "descriptive" (Siegle, n.d.). They focus on examination of the educational and social contexts that affect the introduction and development of STEM in Hong Kong, inside and out of school.

The promotion of STEM education is portrayed by the EDB as a continuous curriculum change. As such, the vision and entailed actions are crucial to the implementation of the initiative (Lawler, 2016). In line with Fullan's notion of "organizational capacities"[12] (Fullan, 2011, cited in Lawler, 2016) for changes and the consideration of the contexts of Hong Kong schools, the focuses and concerns in STEM development revealed in these studies are listed as follows.

In general, respondents to these studies perceive STEM as "hands-on, problem-based learning experiences" (e.g., Croucher Foundation, CF, 2016) which "develop problem-solving, innovative skills" (e.g., HKFYG, 2018). Further-

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at the primary and secondary levels, as well as exploring the initiatives to further enhance teacher training." https://www.info.gov.hk/gia/general/202012/09/P2020120900620.htm

11 e.g. EDB 2015, 2016, 2019, 2020b; Croucher Foundation, (CF) 2016; Agmen Asia and Global STEM Alliance, (AAGSM) 2017; Hong Kong Federation of Education Workers, (HKFEW) 2017; Lee et al., 2017; Geng et al., 2018; Hong Kong Federation of Youth Group, (HKFYG) 2018; The Education University of Hong Hong, (HKEdU) 2019; Policy innovation and co-ordination office (PICO) 2019; Legislative Council Secretariat Research Office, (LegCo) 2020; Ng & Fung, 2020; Ali, M.,2021

12 Including: shared belief, continual professional development, action research, resources, and involvement.

more, they admit that the promotion of STEM in school necessitates the cross-curricular/disciplinary integration of learning elements from at least the three Key Learning Areas (KLAs) of Science, Technology Education, and Mathematics (e.g., Ali, 2021; CF, 2016). However, some teachers feel uncertain about the value of STEM (Policy innovation and co-ordination office, PICO, 2019).

Feedback from respondents in the school context is not so encouraging. For instance, they express the viewpoint that "teachers are too busy and time [allotted to STEM] is not sufficient" and "senior secondary students are too busy" for STEM (HKFYG, 2018). Some responded that "a low priority is given to STEM by school[s]" (Agmen Asia and Global STEM Alliance, AGASA, 2017).

The findings in these studies also reveal how teachers view their readiness to participate in STEM curriculum change. In terms of the affection aspect, respondents expressed their belief that "teachers are not confident about teaching STEM" (HKFEW, 2018) and "half of the teachers are not ready with less than 6% regarding themselves as 'well prepared'" (Geng et al., 2018). Some responded that "teachers are not willing to spend time and effort" on STEM (CF, 2016). The reason may be, as presented by other respondents, that "teachers are without specific knowledge" (CF, 2016), or "an excessive emphasis is being placed on the TK [technological knowledge] rather than the cross-disciplinary aspect of STEM education, i.e., the CK [content knowledge] and PCK [pedagogical content knowledge] " (Ali, 2021) and that they have "difficulties in developing cross-subject/ integrative STEM" (HKFYG, 2018).

The EDB (2016) commits to "Providing learning and teaching resources" and "Enhancing the professional development (PD) of schools and teachers" and other strategies to support the "promotion of STEM education" in schools, yet the respondents in studies show some concerning comments about the rolling-out of these measures. In respect of the PDPs, findings (AFASA, 2017; Geng et al., 2018; HKFEW, 2018; HKYFG, 2016; PICO, 2019) indicate the position that there is a "shortage or inadequate teacher training," "not enough opportunity," and even "concern over the availability of PD." In particular, feedback reveals "concern over the organising of instruction activities to implement lesson[s] smoothly" (Geng et al., 2018) and "insufficient information on selection criteria for KLAs/ implementation approach for organising integrative STEM learning activities" (Ali, 2021). The same occurs in findings regarding the resource aspects. That is, there are "concerns over availability of resources and teaching materials" and "pedagogies support " (Geng et al., 2018; HKFEW, 2018; PICO, 2019). Lastly, in terms of policy aspects, feedback (Geng et al., 2018; HKYFG, 2016) shows there are also "concerns over the task and process of implementing STEM," and "the implementation process is not sustainable and extensive enough in territory-wide coverage."

Along with the descriptive studies discussed above, there are research reports that introduce "intervention" (Siegle, n.d.) into various aspects of the STEM curriculum change (e.g., construction of "STEM Assessment for Hong Kong (SAHK)" in Ng and Fung (2020) to facilitate teachers' practices in undertaking integrative STEM and to generate knowledge to inform future development. Some other interventive endeavors which focus on change-capacity building have been chosen for discussion in the latter section "Current STEM education reforms and policy." The responses and recommendations from these studies have provided input and insights to inform the implementation of STEM.

STEM environments

Under the principle of "STEM for ALL" (CDC, 2015, para. 7-ii; Task Force, 2020, p. 33), STEM is regarded as an entitlement for all primary and secondary students. As revealed in the "STEM Education in Secondary Schools: Improving Resource Utilization" (HKFYG, 2018) studies, 78.8% of responding schools (primary and secondary combined) started to promote STEM education after receiving the one-off grant in the 2015-2016 school year. And in a paper replying to the Legislative Council Panel on Education on STEM (EDB, 2020b), the EDB stated that the response rates of a Bureau-commissioned questionnaire survey on the implementation of STEM education in schools and primary and secondary school were 64% and 73% respectively. As such, it would not be fanciful to assume that the current percentage of schools implementing STEM is around 65% to 80%.

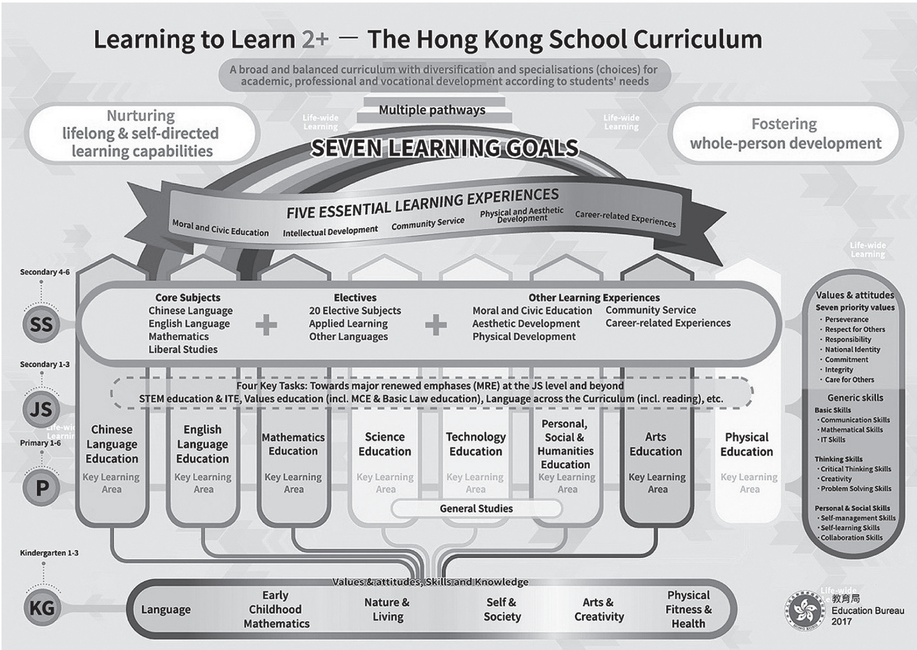
STEM Education System/Framework

It is expected that the STEM education framework will provide directions to guide its implementation in schools. As mentioned earlier, STEM education was promoted as part of a continuous curriculum change. Therefore the venture into the exploration of the STEM education framework will have to start from a wider context of the Hong Kong school curriculum.

The Hong Kong School Curriculum Framework[13] has an open and flexible design with “three interconnected components: (1) Key Learning Areas, (2) Generic Skills, (3) Values and Attitudes” (CDC, 2014; a similar statement appears in CDC (2017a) for secondary schools) to provide description rather than prescription of the way learning experiences in schools are developed with the school background and characteristics of students in mind.

13 https://www.edb.gov.hk/attachment/en/curriculum-development/renewal/Guides/SECG%20booklet%202_en_20180831.pdf [Accessed April 2022]

Figure 1 Hong Kong school curriculum framework[14]



Since STEM education is depicted as a key task, there is no STEM education curriculum framework. Therefore, teachers will have to go back to the two STEM education policy documents, Overview (CDC, 2015) and Report (CDC, 2016) to look for the recommendations for implementation.

Purpose, aim, and objectives

As mentioned in former sections, in order to nurture local innovative and technological talent, the aim of STEM education is presented in the Preamble section of the Report as follows:

> Apart from cultivating students' interest in Science, Technology and Mathematics, and developing among them a solid knowledge base,

14 https://www.edb.gov.hk/en/curriculum-development/renewal/framework.html [Accessed April 2022]

> we aim to strengthen students' ability to integrate and apply knowledge and skills across different STEM disciplines, and to nurture their **creativity, collaboration and problem solving skills,** as well as to foster their **innovation and entrepreneurial spirit** as required in the 21st century (CDC, 2016, Preamble; underline added).

The objectives are presented in the "proposal"[15] sub-section in "Chapter 2 The Policy Context, Purpose and Guiding 6 Principles" as follows (with wording similar to the aim statement omitted):

> The objectives of promoting STEM education are to develop among students …ability to integrate and apply knowledge and skills to solve authentic problems, … so that students are better equipped for further studies and careers... (CDC, 2016, para. 2.4; emphasis added)

Content/ learning experiences selection

From the EDB's words to the Legislative Council Panel on Education:

> "In the initial stage of the promotion of STEM education, some stakeholders … said that STEM education should be a separate subject with a framework to guide the implementation of STEM education by schools. With the EDB's support measures for schools put into effect in recent years, the school sector has generally come to understand that STEM education is **not** to be an independent subject … (EDB, 2020b, p. 2, para 5; emphasis added)

From the Report, the recommendations regarding knowledge and content reference are:

> The updated KLA Curriculum Guides of Science, Technology and

15 There is a sub-section "Final Recommendations" at the end of the chapter. However instead of further elaboration of aim and objectives statements, only guiding principles are laid out in the section. Therefore the objectives in the "Proposal" sub-section are used.

> Mathematics Education... would serve as useful references for schools on the design of school-based curriculum, learning and teaching, as well as assessment for the three KLAs, with recommendations also given on the flexible use of curriculum time, more cross-KLA collaboration and strategies to embrace learner diversity (EDB, 2020b, p. 2, para 3.16; emphasis added).

This implies that there is no "meta-framework" of STEM education prescribed, but instead there is the delegation and entrustment of the "knowledge-aspect" of STEM education to the three KLAs Frameworks, including the skills and values and attitudes requirement.

Method, including organization and delivery of learning experience

The frequent use of the phrase "integrate and apply" in the Report denotes the key role of integration in the implementation of STEM education. Further, there are statements which are used to refer to the need to undertake curriculum integration and to conduct cross-disciplinary learning of the three KLAs by schools and teachers (CDC, 2016, para. 3.3, para. 3.22, para. 6.7, etc.). It also clearly implies the need for cross-curricular collaboration among them.

For the organization of learning experiences, the Report stipulates two approaches to implement hands-on STEM education in Hong Kong schools that enable the integration and application of knowledge and skills across the three KLAs. They are:

Approach One: Learning activities based on topics of a KLA for students to integrate relevant learning elements from other KLAs.

Approach Two: Projects for students to integrate relevant learning elements from different KLAs.

Figure 2 Learning activities organization *Approach One*

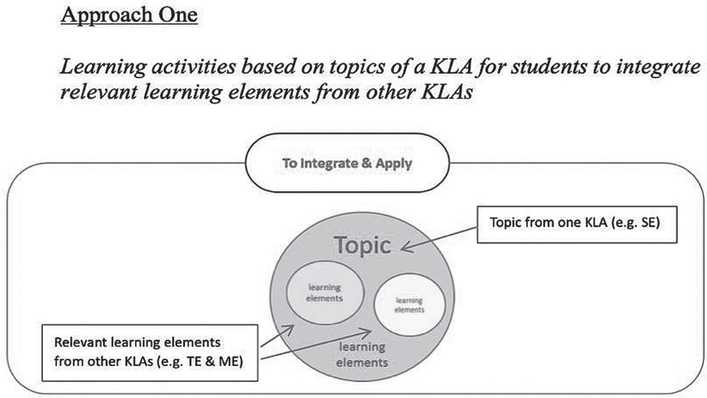
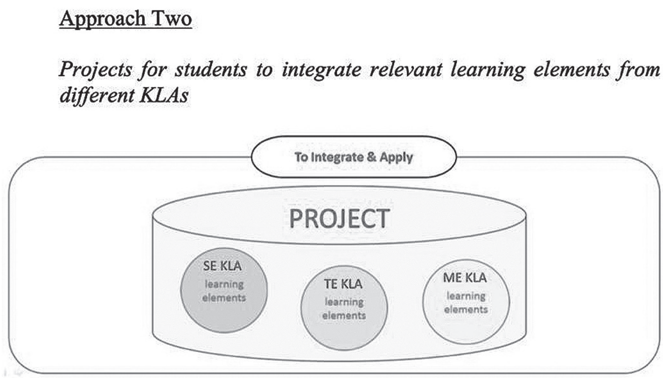


Figure 3 Learning activities organization *Approach Two*



In light of these two approaches, specific pedagogies including "scientific investigation, project learning, problem-based learning, design and make activities and mathematical modelling" (CDC, 2016, para. 3.2) are also suggested.

Assessment

There is one point in which the Report states the stipulation regarding assessment:

“Regarding the assessment for STEM-related learning activities, it should align with the learning objectives as well as the pedagogies adopted to reflect the learning progress and the capability of students as independent/collaborative learners” (CDC, 2016, para. 3.28).

It is not unsafe to say in the same vein of “content-entrustment” discussed in the former paragraphs, that teachers and schools also have to rely on the design of assessment of STEM learning activities organized on the updated curriculum guides of the three KLAs.

Moreover, five guiding principles for promoting STEM education are listed in the “Final Recommendations” sub-section in Chapter 2. They are:
(a) Adopting a learner-centred approach
(b) Enhancing essential learning experiences
(c) Striking a balance
(d) Building on strengths
(e) Promoting STEM education as a continuous and dynamic improvement process

The first two principles may be regarded as supplementary to the objectives of STEM education for the formulation of assessment criteria.

Types of K-12 schools offering STEM education

It is stated in the Report (CDC, 2016) that “To better prepare our students …., STEM education …is essential for their lifelong learning and whole-person development.” With identical statements in the Hong Kong Curriculum Framework, it is very likely that the scope of implementing the curriculum change of STEM education covers all primary through General Studies (GS) and the three STEM KLAs in secondary schools. As senior secondary students have to select two to three electives to study and sit for the HKDSE, STEM learning will be offered to those who opt for STEM-related subjects. As mentioned previously, the implementation of STEM depends on the readiness of teachers and schools, teachers' expertise and interest, and connection with external resources: teacher associations and NGOs, businesses and vendors, industries, and academics in universities. Therefore STEM learning experiences vary across schools.

STEM-related Activities in Non-formal Education

Right after the EDB proposed STEM promotion in schools (CDC, 2015), the Croucher Foundation initiated research (CF, 2016) to examine out-of-school efforts by teachers and schools, community, and academics to promote STEM. One of its efforts is to "detail out-of-school STEM learning programmes held in Hong Kong between June 2015 and May 2016 for students aged from 6 to 18" (CF, 2016). The tell-tale visual portrays the 1,047 out-of-school activities from 144 organizers divided into three groups, namely government-related organizations and schools, NGOs, and private companies. The activities recorded include competitions, exhibitions, talks, workshops, courses, field trips, and camps, whilst workshops and courses combined take up over 80% of the total number. This shows there was great interest and demand for STEM from young students and their parents at the height of its initial introduction. One point of particular interest is that around one-third of the organizers were private companies, which make formidable partners for the government-related organizations and schools (comprising slightly less than half of the total number). Regarding types of activities, unsurprisingly most belong to the Science subject (481/1047, CF, 2016) and take up more than half of the total number when the co-subject (e.g., STEM, Science & Technology, Science & Engineering, among others) activities are also counted. Moreover, in terms of target year level, there are 413 activities organized for the primary group, which is more than that organized for junior and senior secondary.

Further, in the "Supporting Policy for Frontline STEM Teachers Research Report" (HKFEW, 2018), it was reported that the faculties of science and engineering of local universities organized STEM education summer programs for secondary students with a view to enhancing their understanding of STEM through interdisciplinary approaches.

From 2015 onwards, associations of different subject disciplines including science, computer education, and IT have also contributed to the promotion of STEM to teachers and students through the organization of IT workshops, seminars, competitions, sharing, exhibitions, and exchange tours. The topics of these events include AI, embedded systems (e.g., micro:bit), VR/AR, coding, robotics, and CAD software.

STEM Learning Assessment and Career Development

Metrics/indicators defining the success of STEM at system-, school-, program- and student-level

The "Expected Outcomes" stated in the Report (CDC, 2016) mentioned previously can be regarded as the indicators to chart the effectiveness of STEM education at the system-, school-, program- and student-levels. They are written in the form of goal statements describing the directions. For example:

School level

- schools *could* enhance their capacity through <u>engagement</u> of various <u>stakeholders</u> and the <u>community</u> at large to enhance student learning.

System level

- The communication and partnership with local and non-local professional bodies, tertiary institutions, government and non-government organizations would be enhanced in order to foster synergy within the community for facilitating student learning.

Having said this, as the EDB has committed to the "6 Strategies of supportive measures" as part of its main efforts in the promotion of STEM, it is sensible to regard them as the System-level indicators.

International tests can also provide evidence of the effectiveness of promoting STEM. As revealed by the scope of Hong Kong students in the Programme for International School Assessment (PISA), the intent of the STEM curriculum change to foster students' understanding in science is yet to be delivered.

There are some aspects in the performance of Hong Kong students observed in PISA from 2006 to 2018, including:

- ranking in science competence fell from 2nd in 2006 to 9th in 2018; although the ranking was the same as in 2015, the mean score decreased from 523 to 517;
- the percentage of "high-achievers" decreased by 8.1% from 2006 to 2018 (LegCo, 2020)

As the nurturing of "…a versatile pool of talents with different sets and levels of skills to enhance the competitiveness of Hong Kong" (CDC, 2016) is the goal of promoting STEM in schools, the career development of students can also serve as an indicator of accomplishment. The path for STEM career development after junior secondary levels may include but is not limited to:

- Opting for STEM-related elective subjects (e.g., the three science subjects, subjects in technology education KLAs)
- Taking advanced mathematics modules which are required for studying certain STEM courses in university
- Taking a career-oriented "Applied Learning course" in lieu of elective subjects
- Choosing STEM-related undergraduate courses in university.

As revealed in the study by the Research Office of the Legislative Council Secretariat (LegCo, 2020), there are:

- 50.5% of HKDSE Examination candidates who did not take any Science subjects in 2019

- a decline in the enrolment rate of Secondary Six students in advanced mathematics from 22.9% in 2011-2012 to 14.4% in 2018-2019 (LegCo, 2020).

Although the percentage of students who graduated from the University Grants Committee (UGC) funded STEM-related undergraduate courses (i.e., science, engineering, and technology) is maintained at around 34% to 36% (www.statista.com, 2022), they "…fail to attract students with the best academic results…" (LegCo, 2020).

STEM Teacher Qualifications, Pre-service Training, and In-service Professional Development

Given the positioning of the promotion of STEM education, there is no STEM teacher qualification requirement nor STEM-majored pre-service training stipulated in the two policy documents (CDC, 2015, 2016).

As part of its commitment to providing supportive measures for the promotion of STEM, the EDB offered three categories of PDP, namely (1) planning of a school-based cross-disciplinary STEM curriculum, (2) enrichment of knowledge, and (3) introduction of appropriate STEM teaching and assessment strategies (CDC, 2016).

In the paper submitted to the Legislative Council Panel on Education (EDB, 2020b), the EDB presents the PDP organized from 2016 as follows:

Table 2 Professional development programs organized by the EDB from 2016 onwards

Categories	**Whole-school interdisciplinary Curriculum Planning**	**Knowledge enrichment**	**Introducing STEM-related teaching and assessment strategies**
Title	Intensive Training Programme (ITP) on STEM Education	Training Courses on Coding Education	
Period	school year 2017/18 to 2019/20	school year 2017/18 to first term of the 2019/20	
No. of Batch/ phase	5 batches	5 phases	
Participants	6,300 teachers from 500 secondary schools and 5,400 teachers from 400 primary schools	Basic course: 770 teachers from 320 schools Advanced course: 300 teachers form 200 schools	
Further development (2020 onwards)	• Sharing sessions and workshops to assist school leaders in planning school-based curriculum	• Pilot course started in Dec 2019 to further enhance primary teachers' capacity in coding education • New courses on information technology (IT), AI and 5G communications • Visits and exchanges to the Greater Bay Area to understand technological development and the application of innovative technologies	• A new round of ITP will also cover the introduction of teaching and assessment strategies.

Alongside efforts of the EDB to provide in-service PDPs, there are training courses organized by local universities, for example:

- The Education University of Hong Kong organized STEM Education Seminars and teacher training courses on knowledge enrichment in coding through the "Coding Education Centre" and "STEM Ed Lab" (HK-FEW, 2018)

- The CityU APP Lab (CAL) of the City University of Hong Kong organized "Hour of Code" events to provide services on coding education to teachers.

Current STEM Education Reforms and Policy

As discussed in the previous sections, it is clear that STEM education is promoted as part of the curriculum renewal (CDC 2016). As well as the aforementioned PDP and seminars organized by the EDB and universities, there have been efforts and interventive research from academics and professional organizations in order to address the complexity of the curriculum change of STEM promotion and to enhance teachers' readiness for its implementation. The following two endeavors have been chosen for discussion as both of them focus on change-capacity building that comprises the following features:

- deliberation on the purpose of STEM curriculum change;
- suggestions for teacher PD;
- interventions covering several aspects of implementation including comprehension of the aim of STEM education, related curriculum design and organization, instruction design of learning activities, and the consideration and design of assessment; and
- collaboration with frontline teachers and schools in try-outs and the refining of the original proposal

Integrative STEM efforts by the education university of Hong Kong

In response to the introduction of STEM education, the "STEM Education: From Theory to Practice" (Lee et al., 2017) was published and initiated by the Department of Science and Environmental Studies of the Education University of Hong Kong (HKEdU) with a view to providing teachers with a summary of literature from foreign countries to formulate a theoretical basis for STEM implementation. From that, a set of guidelines was also proposed to inform teachers undertaking the planning and offering of integrative STEM education.

Based on this guideline and with the funding from the Quality Education Fund Thematic Networks (QTN) scheme of the EDB, the “From Self-Directed Learning to the Integration of STEM into School-Based Curricula of Primary and Secondary Schools” project was launched to provide school-based curriculum and instruction design support and related PD to participating primary and secondary schools. In the two cycles (i.e., 2017-2018 and 2018-2019) of incremental interventions in the participating schools, the project team furnished support to schools and also facilitated the design and trying-out of integrative STEM learning activities. The succeeding document, “Teaching Colourful STEM: The professional development path of 14 primary and secondary schools” (HKEdU, 2019) was published to showcase the achievements of participating schools in the first cycle. There are chapters devoted to the discussion of the rationale, purpose, and characteristics of integrative STEM (HKEdU, 2019, p. 4, adopted from Sanders, 2009) and the introduction and elaboration of recommendations and guidelines for STEM implementation that are distilled and summarized from the findings in the first cycle, including “strategies in implementing integrative STEM,” “modes of curriculum organization,” “Objective design framework,” “Instruction Design framework,” and “Assessment framework” (HKEdU, 2019, pp. 95-119)

It is observable that the HKEdU endeavor to implement STEM is largely accommodated with the rationale and recommendations stipulated by the EDB (CDC, 2016) in terms of the goal of STEM education being to develop students’ 21st century skills, including problem solving, creativity and innovation, the ability to integrate and apply knowledge and skills from STEM disciplines, among others. The STEM learning experiences are to be cross-curricular, related to daily life problems, and essentially hands-on and minds-on in nature (Lee et al., 2017). The "engineering design process" (as mentioned in CDC, 2016) is adopted as the procedural guide to support students' problem solving (Atman et al., 2007; Hynes et al. 2011, cited in Lee et al., 2017).

CEATE Awardee Workshop

The "CEATE Awardee Workshop" (CAW) is a professionally initiated bottom-up endeavor led by three awardees of the Chief Executive's Award for Teaching Excellence (CEATE) in the Technology Education KLA. The project titled "CEATE Awardee Workshop (D&T)" was first formed in 2018. Ten Design and Technology (DT) teachers were recruited. From 2019 onwards it was renamed the "CEATE Awardee Workshop (STEM)" (CAW) to address the vast demand from teachers and schools to implement STEM education. Thirty STEM-related subject teachers from 25 schools were recruited. In view of the increasing demand, the membership expanded from 2021 onwards along with the provision of opportunities for new teachers to participate in training on conducting hands-on practical lessons.

The aims of CAW are to gather and formulate a professional knowledge base for teaching DT and STEM, and to share knowledge with local and global TE and STEM communities through paper presentations, which resonates with the crux of Fullan's notion of capacity building of "Organizational capacities" (cited in Lawley, 2016) in the implementation of curriculum change.

The following aspects are the focus of the efforts of CAW in supporting the capacity of DT and STEM teachers:

- To identify existing planning and pedagogic practices that support students' learning in problem-solving design projects with tangible media
- To optimize evaluation for accelerating students' learning
- To implement online teaching strategies for hands-on practical projects
- To enhance teacher training in STEM education

- To enhance learning effectiveness via STEMaker education

The notion of STEM that underpins the practices in CAW:

> The goal of STEM education is to cultivate students' *STEM literacy, anthropocentric perspective and entrepreneurial mindset through problem-solving* *projects*, so that the younger generation can *integrate* and *apply knowledge* and *skills* from different subjects by incorporating an *engineering mindset via technological means and design cycle to innovate and solve real-life problems. It heavily stresses the development of our younger generation into innovative and entrepreneurial talents for the 21st century.* (Adopted from Guangzhou Hong Kong and Macao STEM Education Alliance, 2018)

It is obvious that the DT tradition and the notion of STEMaker education (Wan & Wong, 2016) pervade the purposes and practices of the CAW. The project-based learning that is undertaken via the design cycle is subscribed as the primary form of learning experience organization of the practices in CAW. It is believed that the real-life scenarios set in DT/ STEM projects that espouse diversified inputs and requirements can contribute to students' creativity enhancement.

Trends and Issues in STEM Education

The study of trends and issues in STEM education can provide insights and direction for understanding changing contexts and planning strategically (Wicklein, 1993) for the development of change in the mid-term and beyond.

In the preparation of this manuscript, the discussion of trends and issues is supported by three sources:

- literature cited and referred to in the previous sections, including STEM-related government documents, research reports, and survey findings;
- interviews with frontline teachers who are STEM leaders in schools; and
- statistics of posts for promotions and information of events/activities held from 2016 to 2022 that were circulated on three STEM social media platform groups[16].

Frontline teachers[17] were invited to be interviewed as they were the STEM Coordinators (STEM-Co) or assumed similar duties. They were responsible for implementing STEM in their schools, and thus all had experience to differing extents of curriculum planning and cross-disciplinary integration. Open-ended questions were set to ask for their views on "current trends & issues" and "future trends & issues." Occasional follow-up questions were proposed to clarify the meaning or to prompt for further information. Pseudonyms were used in the transcribing and reporting.

The three social media platform groups under this study were formed with more than 100 members, each with difference emphases.

16 For the purpose of this manuscript:
- Only open promotions of event/ activities appeared in these groups that were also promoted publicly outside the group will be used.
- Anonymity of any parties (association, university, particular person) will be kept and pseudonyms will be used for the titles of the groups and parties involved so that no parties can be recognized.
- Data will be amalgamated and reported in a collective manner without showing the trait of any particular party.
- The author will work meticulously to achieve the accuracy of the data and will take full responsibility in this regard.

17 N = 6. Teaching experience: over 20 years = 1, over 10 years = 1, less than 10 years = 4. Subject background: D&T, ICT, Physics, Chemistry and Biology.

Group A was formed in 2016 (i.e., right after the introduction of STEM education by the EDB) with the purpose of exchanging information about STEM-related activities promotion, solutions in implementation, and opportunities in schools. In the context of this manuscript, the tallies focused on STEM event promotion. Given that this group was one of the most popular among STEM-related social media platforms and entailed a huge volume of posts, the scope was narrowed to posts by two associations, identified here as association A and association B, from 2016 to April 2022. The subject background of the A and B associations are computer education and IT respectively, and they are the parties that uploaded most of the posts in the group.

In order to allow for an examination to chart the shifting trend throughout a specific period, posts of events promotion from 2016 to 2017 uploaded by other parties in Group A were also recorded. The significance of this set of data lies on its reflection of the trend in the period when STEM was beginning in Hong Kong.

Group B was formed by teachers of technological subjects (e.g., DT, Design and Applied Technology) and was set up in 2013. Group C took on the mission to promote the Maker movement. It was formed in 2017.

Table 3 Overview of the statistics of posts promoting events/activities in 3 STEM social media platform groups

Social Media Platform Group	A	B	C
Period of Events/ Activities Recorded	2016- 2022 (April)	2013- 2022 (April)	2017- 2022 (April)
No. of Promotion of Events/Activities Counted	738 (584)*	135	63
No. of Relevant STEM Events/Activities Logged for Further Analysis	525 (435)*	95	23

Table 3 (continued)

Percentage of Nature of Events/Activities	A	B	C
On Curriculum Development, Cross-Discipline Integration.	0.0%	5.8%	0.0%
PDPs, Workshops, Knowledge Enrichment Sessions.	11.8%	29.7%	6.3%
Seminars, Sharing Sessions	40.0%	24.5%	49.2%
Competitions#	21.4%	16.8%	20.6%
Other Activities: Conference, Visits, Exchanges Tour, Camp for Students etc.	28.0%	23.9%	25.4%

*Figures of 2 associations only

#Mainly for students.

Following Wicklein (1993), Moye et al. (2020) identified eight categories of current and future trends and issues in Technology and Engineering Education. They were adopted with the consideration of the Hong Kong context to examine the three sources mentioned above, from which the trends and issues in STEM education are identified and discussed in the section below.

Trends in STEM Education

1. Official positioning of STEM: more a curriculum renewal than a formal discipline of learning

STEM is situated in the Hong Kong Curriculum Framework[18] as one of the four impermanent "Key Tasks" which span the eight Key Learning Areas. As stated in the Report (CDC, 2016), its presence in the school curriculum is under the label "promotion of STEM education" (CDC, 2016). This implies that STEM education is not a subject in its own right. The learning experiences related are very likely to be cross-disciplinary.

18 https://www.edb.gov.hk/en/curriculum-development/renewal/framework.html

Having said this, the EDB is aware of the complexity of the STEM curriculum change and the importance of building in change capacity for teachers and schools. Therefore, strategic supporting measures are proposed as follows:

(1) Renewing the curricula of the Science, Technology and Mathematics Education KLAs;
(2) Enriching learning activities for students;
(3) Providing learning and teaching resources;
(4) Enhancing the professional development of schools and teachers;
(5) Strengthening partnerships with community key stakeholders; and
(6) Conducting review and disseminating good practices.

In terms of funding provided to support the implementation of STEM, the EDB explains that there are so far four categories of grants and funding[19] committed to support the promotion of STEM education.

<u>"IT Innovation Lab" in Secondary Schools and "Knowing More About IT" in Primary Schools Programmes</u>

Funding of $500 million was originally proposed by the EDB (2020b) but eventually was allocated to the Office of the Government Chief Information Officer (OGCIO) to implement the programs "Enriched IT Programme in Secondary Schools" (EITP, may also be referred to as "IT Innovation Lab") in December 2020 and the "Knowing More About IT" in Primary Schools in July 2021 in three school years from 2020/21 to 2022/23. Subsidies under these programs to secondary and primary schools are $1,000,000 and $400,000 respectively.

19 The PPT presentation "Development of STEM education in Hong Kong" by YUNG Po Shu, Benjamin, Principal Assistant Secretary (Professional Development & Training), EDB (2020b) and OGCIO (2021) were referred to and adopted in preparing the discussion on funding.

Life-Wide Learning Grant

Starting from the 2019/20 school year, the Life-Wide Learning Grant with an annual provision of $900 million has been provided for public schools to support them in taking forward life-wide learning, including humanities, STEM-related learning activities, and other different curriculum areas, with enhanced efforts on the basis of their present foundation.

One-off STEM education Grant

In the 2015/16 and 2016/17 school years, the EDB provided funding of $100,000 and $200,000 to each primary and secondary school respectively to support the advancement of STEM education. Schools could purchase equipment and resources, as well as support students to participate in STEM learning activities.

Quality Education Fund (QEF)

The QEF has included STEM education as one of the priority themes for application. In 2018, the QEF allocated $3 billion to establish the "Dedicated Funding Programme for Publicly-funded Schools." With a ceiling of $2,000,000, schools may apply QEF for funding to carry out school-based curriculum development and student support measures, including the support for school-based STEM education programs. Up to April 2020, more than 180 dedicated funding programs with STEM-related themes, and with total funding granted amounting to over $170 million, were approved by the QEF (EDB, 2020b). The Quality Education Fund Thematic Networks (QTN) is another channel to encourage outstanding STEM-achieving schools and interested tertiary initiatives to act as a coordinating STEM QTN hub to provide supports for STEM promotions for schools in need.

It is worth noting that the three QTN projects reported by the EDB are tied-up with the co-theme "Self-directed Learning (SDL)" (EDB, 2020b). Besides the one that is undertaken by HKEdU and has been reported in the former Section 2.6, two projects are from the University of Hong Kong (HKU), namely "Self-Directed Learning as a Strategy to Promote STEM Education" by the e-Learning Development Laboratory, Department of Electrical and Electronic Engineering, and the "Integrated Self-directed Learning Approach to School-based STEM Development (In-STEM)" by the Centre for Information Technology in Education (CITE), Faculty of Education.

2. Authentic hands-on problem solving as a core learning experience in STEM

For the very first time the DT/Technology Education type of hands-on, problem-solving learning has come to center stage on the Hong Kong education scene.

Reading the objectives in conjunction with the following statement (f) in paragraph 2.3 of the Report can provide the reader with the compelling reasons for highlighting the practical aspects of problem-solving skill development:

> "Students were found to focus on acquiring knowledge of individual subjects and may not evenly participate in hands-on activities in schools. Therefore, it is necessary to strengthen their ability to integrate and apply their knowledge and skills across different subject disciplines through s<u>olving daily life problems with practical solutions</u> and <u>innovative designs</u>" (CDC, 2016; emphasis added).

The addition of the modifier "authentic" (CDC, 2016, para. 2.4) accentuates the importance of the construction of appropriate contexts in which problem-solving skills can be enhanced.

The intent to provide hands-on, design-and-make learning for all students to nurture their capabilities to solve authentic problems in life is regarded as an important feature of STEM education in view of its potential and extent to enable the next generation to contribute to the prosperity of Hong Kong.

As stated in the Report, this intent is well-received by teachers and schools as "[T]hey shared the view that the provision of hands-on learning activities for students to solve authentic problems is essential" (CDC, 2016, para. 3.6).

The EDB stipulates two approaches (CDC, 2016) to implement hands-on STEM education in Hong Kong schools. In Approach One, the outcomes of the learning activity focus more on the acquisition of subject-based concepts and knowledge, thus it can be coined "*STEM education for understanding.*" Approach Two is a D&T type of problem-solving project that integrates learning elements across Science, Technology, and Mathematics. As the outcome of learning will bring about the creation of products to serve client's needs, it can be coined "*STEM education for innovation.*" This is in line with the advocacies of CAW STEMaker education regarding design projects mentioned in the previous section, and the belief that the STEMaker project is the better way to nurture creativity and innovative capabilities in students. The EDB also admits the potential of the learning activities under the second approach that are in the form of real-life situated STEMaker projects (CDC, 2016, para. 4.11)

From the observations of others and their own practices, the teachers interviewed are also aware of the emergence of project-based learning experiences in the realm of STEM that comprise the following features:

- hands-on learning activities
- developing transferrable skills, knowledge, and creativities
- Solving daily problems with tangible outcomes
- Allowing experimentation, exploration, and deliberation (Teachers Bruce, Calvin, Kate, & Tim)

It is therefore clear that the promotion of STEM opens the chance to re-introduce the potential of the authentic problem-solving DT/Technology Education type of hands-on, problem-solving learning to the Hong Kong education community.

3. Diversifying implementations for promoting STEM education by schools

Another important aspect of STEM education in Hong Kong schools is the undertaking of school-based curriculum integration.

Inherently the perceived meaning of S, T, E, M and STEM denotes the necessity of collaboration and integration among STEM-related subjects (Teachers Leon, Tim, & Wise). Also, it is observed that there is a frequent appearance of the action verbs "integrate and apply" in the purpose-related statements in the Review (CDC, 2015) and Report (CDC, 2016). At first glance their presences denote the desirable competence to be developed in students of coping with the authentic daily life problems that involve knowledge skills from a range of disciplines, not limited to Science, Technology, and Mathematics. For teachers it bears the imperative to organize the learning experiences, whether they be in the form of investigative or practical design and make activities in an integrative and multidisciplinary manner.

The integration required not just the matching and selecting of relevant knowledge and skills from the involved subject, but also the consideration of the contextual factors in the school.

The EDB states that it is the responsibility of the "school leaders" to design the learning experiences in STEM "through support to schools on whole-school curriculum planning…" (CDC, 2016, para. 1.6), "…holistically and effectively at school level according to their school context to suit the needs and interests of students" (CDC, 2016, para. 2.7) and "…to effectively use school-based flexible time of central time allocation and outside classroom learning for engaging students in worthwhile learning experiences (e.g., cross-curricular and cross- KLA project learning or competitions)" (CDC, 2015).

This is coined the "School-oriented" policy (LegCo, 2020) in that the EDB allows the schools to decide the STEM education according to their capabilities and undertaking the change with the characteristics of the students in mind.

The freedom to decide espoused diversified implementations of STEM in the schools is observed. It is because school contexts vary in terms of, among other things, subjects offered (and also the subject expertise of teachers), venues and equipment/ resources available, lesson time allocation and time-table, and students' background and previous knowledge. Teachers also differ in their understanding and skills (e.g., Skilbeck, 1976) in analyzing the purpose of STEM and school situation, planning and developing the integrative learning activities, implementing the lesson plans, the teaching of investigations or design and making lessons that are inherently hands-on and minds-on, and the likes.

Faced with complicated change of the promotion of STEM, the implementations of STEM education are very likely "school-oriented" and diversified.

4. The evolving popularity of iconic items in STEM promotion

By iconic items the author means those popular STEM-related topics or artefacts that frequently appeared in dialogues, information exchange, and practices of stakeholders. The discussion of iconic items in STEM reveals both the change of topics incorporated into the learning of STEM and the tactics teachers and schools adopted in STEM implementation, so that reviews on the efforts invested, the directions, and the context of the development of STEM curriculum change could be informed.

In the interviews of STEM-Co taken recently, the items that immediately came to mind are as follows:

Table 4 Iconic items mentioned in transcripts of the STEM-Co interviews

Iconic Items Mentioned	Frequency
Artificial Intelligence (AI), Machine learning	4
Robot (mBot)	3
Python	2
Internet of Things (IOT)	2
Drone	2
Aquaponics	2
Coding	1
3D Printing	1
Computational thinking (CT)	1
micro:bit	1

These items are "hot" topics in teachers' direct experiences of working with STEM, while interacting with colleagues and teachers of other schools, and when hearing people talking about STEM. Unsurprisingly, "artificial intelligence (AI)" tops the list and is followed by the popular AI programming language, Python, and its applications in the "Internet of Things (IOT)." When comparing the teachers' list with the "Statistics of Categories of Posts Promoting Events/Activities in 3 STEM Social Media Platform Groups," the popular items mentioned in the STEM-Co interviews are largely matched popular topics of events and activities promoted in the groups, although there are fluctuations in certain categories throughout the years.

Table 5 Statistics of categories [20] of posts of events/activities in social media platform groups

Ranking in Groups	Group A	Group B	Group C
1st	IT policy related 36.3% (41.8%#)	Design, Project, Hands-on practical lessons 17.9%	IT policy related 21.7%
2nd	Hot IT topics 17.1% (20.2%#)	STEM per se 13.7%%	STEM per se 17.4%
3nd	Coding 13.1% (9.2%#)	Hot STEM items 7.4%	Other policy/ direction & Other STEM subjects 13%
4th	STEM per se (Hot STEM items*) 8.8% (7.8%#)	Robotics 6.3%	Hot IT topics & Hot STEM items 8.7%
5th	Hot STEM items (STEM per se*) 7.8% (6.6%#)	Tech Hot items 5.3%	--

* Rankings when only events/ activities of 2 associations are counted

\# Percentages when only events/ activities of 2 associations are counted

Those mostly mentioned items by teachers belong to the category "Hot IT topics" which are hi-tech popular topics but only rank second in the statistics. The highest ranked category included is "IT policy related" which comprises

20 Breaking down of items into categories: STEM per se: STEAM, STEM, STEMaker, IT policy related: eLearning, information/ Digital Literacy, ICT, CT, IT, IT Innovation Lab, BYOD, Hardware, Network security; Coding: code/ app/ hackathon, Swift, scratch, Python; Hot IT topics: IOT, Smart City/Home, AI, deep/ machine learning, Blockchain / FinTech/ NFT, Cloud, Big Data; Hot STEM items: AR, VR, MR, ER,魚缸珊瑚, Drone, Minecraft; Robotics: Robot, Makerblock, Mbot; Tech Hot items: Aviation/ Flight Sim, Automation, Manufacturing/ production industry; Other policy/ direction: career/startup/ entrepreneurship, Green; Other STEM subjects: Gen Studies, Maths/ Sci

government initiatives and measures including "computational thinking" (CT), "Bring-your-own-device (BYOD)" scheme to subsidize economically-challenged students, "IT Innovation Lab," "eLearning," "school network security," "school IT infrastructure and hardware," and so on.

Since the two associations focused on in the statistics are formed mainly by computer or IT educators and teachers, it is logical that these two categories top the ranking of events and activities tallies. But at the same time, the "IT related policy" also ranks first in Group C which is composed of making-focused stakeholders. This reflects the significance of IT in the STEM communities.

5. Variation in channels of capacity building for STEM curriculum change

No doubt the full-scale implementation of STEM curriculum changes entails great challenges in capacity-building and enhancement of readiness. It is witnessed that in facing the obligatory but yet unfamiliar STEM education promotion, schools and teachers are in great need of professional development support to provide them with the knowledge and skills to offer cross-disciplinary, hands-on, minds-on learning experiences.

From the three sources referred to, some professional development support is top-down, that is, it is offered or supported by the STEM policy[21] and related government funding. This includes the previously discussed PDPs organized by the EDB and the three QTN-funded projects by tertiary institutions, whilst some are organized by NGOs, teacher associations, and resource vendors that are inspired by STEM policy to enhance teachers' knowledge in STEM. Topics of these events by NGOs, tertiary institutes and vendors are in the category "IT policy related," "Coding," "Hot IT topics," and "Hot STEM items." Of

21 For example, "Strategy 4 Enhancing Professional Development of Schools and Teachers" and "Strategy 5 Strengthen Partnerships with Community Key Players" in CDC (2016).

particular interest is that those events organized by resource vendors (which account for 33% of the events in the tallies) are jointly organized by previously mentioned Associations A and B and are largely related to "hi-tech equipment/ hardware."

There are also bottom-up efforts by teachers in particular schools or in learning communities/ networks of several schools to enhance their change capacities in aspects that are tailor-made to cater for the specific needs in their school context. They include, but are not limited to:

- Discussion on the positioning, definition, and identity of STEM in their schools (Teacher Bruce)
- Knowledge in school-based curriculum development of integrative STEM learning activities (CAW)
- Sharing and knowledge enrichment in STEM-related topics conducted by more competent "core team" teachers to spin-off to fellow teachers in the school and the communities (Teachers Kate & Tim)
- Training of capabilities and hands-on skills for conducting practical problem-solving STEM projects through workshops and sessions for teachers (CAW)

Table 6 Variation in channels of capacity building for STEM curriculum change

	PDPs by EDB	QTNs	Events by Associations and vendors	Learning communities/ self-helping network by teachers
Extent of policy-related	Top-down	⟵⟶		Bottom-up
Blessed with funding.	Full	⟵⟶		Least/ no funding
Duration	Less than a week/ one-off	Extend over a period of time, e.g., 2 school years	One-off	Extending over a period of time, depends on opportunities/ spaces available to teachers
On Curriculum Development, Cross-Discipline Integration.	✓	(✓)*		✓
PDPs, Workshops, Knowledge Enrichment Sessions.	✓	✓	✓	✓
Seminars, Sharing Sessions.	✓		✓✓	✓
Training on skills for practical projects/ lessons.			(✓)	✓

Key: less or very few in number (✓), a significant number ✓, greater in number ✓✓

*HKEdU, as interpreted from information available

The positioning of CAW in the efforts of teacher professional development can be regarded as a hybrid of teacher collaboration and professional intervention. One of the main features of the activities of CAW are the lesson observations conducted in 2018-2019 and 2020-2021 on the DT and STEM lessons taught by members. It was observed that the teachers in the first phase had the skills and capabilities of offering hands-on practical lessons, whilst STEM teachers who participated in the second phase did not have the same level of confidence in teaching hands-on practical lessons with manipulation of materials. The need to enhance STEM teachers' confidence in adopting the design cycle in planning and offering the project, especially in the setting of scenario situation, is addressed by the "Training on skills for practical projects/ lessons" as a part of the capacity-building efforts.

Major Issues in STEM

1. Positioning and the clarity of the vision and actions of STEM curriculum change

The vision of STEM education is stipulated in the Preamble of the Report that is tactically "… being **promoted** as a key emphasis in the ongoing renewal of the school curriculum…" (CDC, 2016; emphasis added). It is defined as "… an acronym that refers collectively to the academic disciplines of Science, Technology, Engineering and Mathematics." With a plain explanation of the term, this definitive statement shifts the "responsibility of defining what it is" to "stating what will be done under the label." More efforts on the clarity of the change are expected.

The curriculum elements (aim/ objective, content, teaching approaches) in the Report are stated in different sub-sections (Expected Outcomes, Final Recommendations that states the guiding principles). For instance, the Objectives appear in the Report (CDC, 2016, para 2.4) stipulates the expectations for attainment of students, while on the following page, the statements in the "Expected Outcome" sub-section relating to students' learning outcomes share similar wording with those in "Objectives."

Teachers' comments that the "aim of STEM is too vague," and "…taken by name" (Teachers Bruce, Calvin, Tim, & Wise) show that its implementation is needed to be improved (e.g., Ali, 2021; PICO, 2019). The current central vision is yet to be sufficient to inform the building of shared vision at the school level and the building of consensus on how the change is perceived and undertaken as well (Teacher Tim).

The policy to posit STEM as a "promotion" also leads to the decisions not to endow STEM with a subject status, a curriculum framework to lay out guidelines, and "exemplars illustrating how to undertake school-based consensus building [in curriculum development]" (Calvin), among others. That is also confirmed in the Consultation Document of Task force on the review of the school curriculum (2019).

> "…the pace and implementation strategy of STEM education varies a lot among schools. STEM advocates consider that the Government should step up efforts in promoting STEM education and provide more guidance and support to boost the development of STEM education." (CDC, 2016, p. 10, para. 2.22)

Then there are several other issues which have emerged.

The first is that the previously mentioned entrustment of the content and assessment to the three KLAs makes the "STEM knowledge content look unstable" (Teachers Bruce & Leon). As the initial training of Hong Kong teachers is subject-specific, and they are good at teaching knowledge in particular subjects (LegCo, 2020), it would be a challenge for them to teach a new subject area without a list of content or topic prescription.

Second is about school administrative concerns. The resources, in terms of timetable and person-power, are limited. If STEM does not have a subject status, it is hard for schools to allot curriculum time for STEM in the already packed timetable. It will not be easy to request any subject to surrender assigned curriculum time. In face of the timetable and venue issues, some schools opt to offer STEM as extra-curricular activities or school team activities for joining related competitions (Teachers Bruce & Calvin).

The usual practice of Hong Kong schools is to have the split-class arrangement for Workshop practical lessons due to the concern about safety so as to provide sufficient support to individual students in problem-solving activities. There is a ratio of one teacher to a maximum of 20 students per lesson, which means half of a class. In this sense, the person-power input will be doubled when compared to a normal didactic class. Again, it would be a difficult decision for schools to reserve double the person-power for STEM.

The third issue is funding subvention. In Hong Kong, most of the schools are government or aided, meaning that they are fully subvented by the government and the grants recur annually. As mentioned, STEM is not entitled to subject status. This may explain why the three out of four types of aforementioned funding earmarked to STEM education are non-recurrent and not subject-specific subvention. As such, the monetary resources to STEM are "not so adequate" (Teacher Bruce).

Having said those, QEF is a major source of funding for schools to enhance and upgrade the resources for STEM implementation. Most of the plans submitted to QEF are supported by feasible school-based curricula. On the other hand, Life-Wide Learning Grant provides recurrent subvention for STEM implementation under the schools' discretions.

2. The challenging status of learning in practical problem-solving with and tangible outcomes

Moye et al. (2020) proposed the category, "Technology and Engineering Education (TEE) Identity & Relevance" to depict part of the trends and issues faced by the TEE community, which include, "Poor and inadequate public relations [PR] for TE/ D&T," "TE/ D&T validity and relevance," and "Lack of public understanding and misunderstanding of administrators."

The launching of STEM comes along with some recommendations, for example, "…problem solving to create solutions and make inventions with hands-on and minds-on activities…[E]lements of "design and make" ...incorporated in the learning activities" (CDC, 2016, para. 3.23) that make hands-on practical learning acclaimed as an important feature of the curriculum change. However, the issues of "identity and relevance" appear in the course of "promotion of STEM," which reflects the challenging situation of DT/TE learning.

In the first place, STEM is to be promoted in a collaborative manner among teachers of the related subjects. To include, or not to include DT/TE learning experiences in the STEM implementation is highly dependent on the understandings of the STEM-Cos[22] and teachers involved in the STEM working team of its value in the nurturing of innovativeness and practical problem-solving abilities.

Moreover, the planning and offering of hands-on, practical problem-solving projects requires D&T teaching capabilities. The EDB is aware that:

> "Some secondary schools showed concern over the decline in the supply of Design and Technology (D&T), Design and Applied Technology (DAT) and Home Economics / Technology and Living teachers…" (CDC, 2016, para. 6.8)

Since the shortage and even absence of DT/TE capable teachers is imminent, and as DT and DAT are only offered in around half of the secondary schools, it would not be illogical for schools to choose to implement STEM with less or even without any hands-on design. That would make learning experiences

22 In terms of personal observations and mentioned by STEM-Co, they are predominantly Science teachers.

and "…technology education continue to be overlooked or excluded from many STEM initiatives" (McGarr & Lynch, 2017).

The issue might be rooted in the interpretation of S, T, E & M. As mentioned, the purpose and vision of STEM promotion is not stated clearly enough (Teachers Bruce, Calvin, Tim, & Wise). Schools have to seek their own understanding of the purpose and of planning of learning experiences under the freedom espoused by the "school-oriented" policy (LegCo, 2020).

The context of school decision-making on STEM could be expressed in terms of subject relation. It is noted that some subjects are usually endowed with "stronger subject identity" (Teacher Leon) and have more say in the development of STEM education in schools. In most cases, they will formulate learning experiences and classroom strategies on the basis of their existing subject subcultures (Linblad, 1990; Moreland, 2003; Paechter, 1992). Elsewhere, McGarr and Lynch (2017) remarked on that situation:

> the STEM acronym has quickly gained recognition within the education field as a 'catch all' term encompassing all…activities within the educational system…such grouping does not recognise the existing subject hierarchies and inequalities in provision and participation amongst STEM (McGarr & Lynch, 2017, p. 52).

The expression by a frontline teacher of "tension on hands-on vs. STEM" (Teacher Leon) further evidences the inclination of STEM learning in schools. These curriculum decisions resulted not just from the change-adopting tactic to resort to existing subject subculture by subjects with stronger identity, they are also in line with the "Approach One" implementation (CDC, 2016, para. 3.2).

Although those activities incorporate hands-on activities of investigation, exploration, and experiments, among other things, they are mainly regarded as "STEM education for understanding" with a view to "…cultivat[ing] students' interest in Science, Technology and Mathematics, and developing among them a solid knowledge base…" (CDC, 2016, para. 3.2).

Furthermore, IT or related topics make up 68.4%[23] of the events in Group A. In the Curriculum of Hong Kong, one of the goals is to "…enable students to…use information and information technology ethically, flexibly and effectively…"[24]. As well, "STEM education & ITE" is stated as one of the Key Tasks. These invite question that IT may be a dominant concept in the STEM curriculum change.

All in all, it should be cautious about the tendency to overlook the roles of hands-on practical learning with tangible outcomes in STEM, and the virtue of "getting your hands dirty" in the arduous course of problem-solving and Innovation. If these trends stand, it would invite the question of whether this is beneficial to "Minds-on & Hands-on" (CDC 2016) STEM for innovation as well as the "STEM for understanding" that incoporate the integration and application of knowledge of science, mathematics and IT in solving daily-life problem.

Having said this, the **CAW** carries on to provide evidence to reinstate the possible contribution of TE to STEM. In view of the imperative of "incorporating technological means to innovate and solve real-life problems," CAW strives to develop front-line teachers' competence in carrying out hands-on practical activities, and there are extra sessions particularly offered to new teachers to enable them to undertake and teach hands-on skills.

Therefore, CAW develops and puts forward the following concepts and practices with a view to supporting teachers in planning and offering STEMaker projects:

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23 Percentages of "IT policy related," "Coding," and "Hot IT topics" combined

24 https://www.edb.gov.hk/en/curriculum-development/renewal/framework.html [Accessed April 2022]

- "Five Features of Project-based learning in DT/STEMaker projects" (Leung, 2021),
- Design Cycle (Leung, 2019)
- 4 types of Problem (Leung, 2019)
- 8 levels of STEM activities observed in Hong Kong STEM education (Leung, 2019)
- Engineering thinking/ habit of mind (Leung, 2017b)
- Creativity Space (Leung, 2019)
- Situation and scenario in STEMaker Projects (Wan, 2021)
- Elements of Teacher Capability in Undertaking STEMaker: DT/ STEMaker-project-specific Pedagogical Content Knowledge (PCK) and the common elements of Pedagogical Reasoning and Action (PRA) and the desirable qualities and attitudes in teachers that contribute to the learning in D&T Projects (Wan, 2019)
- Online teaching strategies for hands-on projects (Wan, 2021)

3. Implications of the "partial curriculum" status to the STEM implementation

It is argued that the promotion of STEM can be characterized by the fact that there is no subject-status and a "partial-curriculum framework" on implementation making reference to the three KLAs.

In the Research Brief "*Nurturing of local talent*" prepared by the Legislative Council Secretariat Research Office (2020):

> Under the "school-oriented" policy, EDB allows schools the flexibility... Yet, the approach has been criticized for being too "loose"… problem…is that the efforts to promote STEM education are planned by schools themselves…As such, some schools inevitably encounter problems and obstacles when implementing STEM education (LegCo, 2020, para. 2.4-2.5)

STEM is rather a complicated change which requires the understanding and capacity to undertake curriculum integration in collaboration with teachers of other disciplines, specific PCK(s) (Ali, 2021; Lee et al., 2017; Shulman, 1986; Wan, 2019) to facilitate students' integration and application of knowledge and skills across several disciplines.

Given the absence of a curriculum framework or Handbook (Task Force, 2020) the recommendations in the Report (CDC, 2016) are not easily to be translated into curriculum planning actions.

Adding to the fact that Hong Kong teachers are trained under specific disciplines and the EDB committed PDPs are far from sufficient to address their capacity-building needs in undertaking integration (see e.g. AFASA, 2017; Ali 2021; Geng et al., 2018; HKFEW, 2018; HKYFG, 2016; PICO, 2019; Teachers Kate, Leon, & Wise), thus "…little progress has been made." In the current efforts in STEM there are "superficial integrations" (Ali, 2021), or else teachers resort to the original subculture and teach in the traditional way (Teacher Calvin). Whilst some schools choose to resolve the challenge by providing pull-out STEM programs outside formal timetables, mostly these are school-team type activities for more able and elite students in STEM, and are not in line with the vision of "STEM for all" (CDC, 2015, para. 7-ii; Task Force, 2020, p. 33).

The absence of a "chart of progression" in learning STEM also catches the attention of teachers.

Since there is no roadmap of attainments prescribed, the decisions on the learning experiences are diversified, especially in primary schools. As described by teachers, some more able schools with more resources, community support, and capable teachers can provide a wider range of STEM learning experiences to pupils, whilst in schools where STEM has lower priority, pupils' experiences in STEM learning are limited. This leads to the problem of “discontinuity in transition” (Stables, 1996) from primary to secondary school. Secondary teachers (Teachers Kate & Tim) mentioned that on the certain occasions “micro:bit” was adopted in a STEM activity, it was really hard to cater for the wide range of learning diversity among the students. Since students come from different primary schools, they have different extents and breadths of previous knowledge: some were really expert in playing with the “micro:bit” while others were all the way struggling to cope with it.

In view of the lack of a “Chart of progression” for learning STEM, CAW adopted a framework of “Focuses at Different Levels of Schooling” in the former version of the TEKLA Curriculum Framework (CDC, 2000) to probe for the conception and content of progression in STEM learning, which is listed as follows:

Key Stage 1 & Key Stage 2 **Awareness, Exploration, and Experiencing**
Key Stage 3 **Familiarization**
Key Stage 4 **Orientation and Specialization**

At the same time, CAW started to study the development of the “STEM capability indicators by age” (STEM分齡能力指標) with a view to developing a more extensive framework of learning progression in STEM (Leung et al., 2018).

Further, CAW developed the School-Based Curriculum Development (SBCD) Cycle for STEM education to support schools in undertaking the planning and development of integrative STEM experiences for students (Leung, 2017a). The SBCD cycle, along with the related instruments “Learning elements analysis” and “STEMaker Project Planning Form”, can provide guidelines and procedures to plan integrative STEMaker projects for students.

4. Effects of iconic items on the purpose and course of the STEM implementation

It is conspicuous that in STEM teachers' casual conversations, iconic equipment like AI, 3D printing, and so on are frequantly mentioned.

Consider the utilization of the One-off STEM education Grant by schools. Research (HKFYG, 2018) reveals that most of the One-off STEM Grant has been used by schools to purchase equipment. As for the proportion of the funding used, the purchase of equipment was the largest, with nearly 40% of the allowances being spent on these items (HKFYG, 2018, p. 21).

Taking STEM by name/ by popular terms & hardware is not something new. Elsewhere the author has identitied the "resource enhancement" approach (Wan & Lam, 2001), that is, the attempts to update the resources and facilities so as to enhance the image of technological subjects. It has been observed that, when faced with a new initiative, this approach is a usually adaped practice to evade the burden of comprehending the purpose and formulating actions to the change by entrusting the effort of the undertaking of curriculum change to equipment, hardware, or hot STEM items. It follows naturally that some schools choose to use ready-made solutions including products, teaching kits, and teaching programs, or they outsource the workload to private companies and resource vendors (Wan & Wong, 2016).

The statistics of events of the three social media groups show that the above-mentioned iconic items and topics that frequently appear in the statistics in three groups somewhat carry "hi-tech" or "hardware" denotations.

Nevertheless, the value of some items is questionable. One example quoted by a frontline teacher (Teacher Bruce) is that in a sharing session on STEM, a 3-D printed demonstration model that had already existed in other media was presented as "STEM".

Without meaningful reference to the purpose of STEM learning, the value of these examples is in doubt, and that may explain why "most STEM education resources are underused" (HKFYG, 2018, students' p. 23) as teachers are yet to know how to use them in a way beneficial to students' learning.

In some cases STEM is also "taken by name" by parents. Although STEM is widely publicized in the mass media, parents do not quite understand what it is. However, since it is a key task in schools, it is highly promoted by tutorial schools to persuade parents to join STEM courses to equip their children with STEM-readiness in their portfolios for applying to "dream schools" in which they are interested. This "taken by name" leads to the issues of confronting expectations on students' learning and achievement in STEM between parents and teachers (Teacher Bruce).

It has also been observed that the emphases reveal the practice of "outsourcing" to private companies or venders[25] (e.g., CF, 2016,), that is, along with acquiring STEM equipment, schools seek ready-made teaching programs, learning activities, and even teacher development courses offered by service providers (Wan & Wong, 2016). The pitfall of the "readied solution" approach is that these practices are far from a broad, balanced, and comprehensive STEM curriculum, as they do not enable the inclusion of a multitude of learning outcomes and experiences. To make the STEM change a sustainable one, we need to develop the comprehension and contemplate the vision, teachers' understanding and conceptions of STEM learning elements, and their competencies in pedagogy in conducting "big-task" projects (Wan & Wong, 2016)

Considering STEM as hot items /hot topics/ gimmicks does not nurture students' habits of reflection and technology awareness (CDC, 2017c).

25 In the events/ activities recorded in the social media platform Group A, 33% are vendor-initiated, which is similar to the percentage of out-of-school STEM activities (34%) studies stated by the Croucher Foundation (2016)

One of the setbacks of this denotation is that it cuts technological activities off from economic, social, cultural, and environmental contexts, and deprives them of the awareness of the impact of technological innovation on society and the environment. This is the crux of the "Technological awareness" Objective in the Aim of TEKLA (CDC, 2002c) as well as where the "Anthropocentric Perspective" aim of the STEMaker education (Wan & Wong, 2016)[26] is rooted.

By bearing in mind this awareness when undertaking design and making in STEMaker projects, students will make sense of the technological phenomena they are situated in and can develop their abilities on the part of citizens to predict, control, and manage critically the behavior and outcomes of technological systems which are more crucial in this respect (TAA, 1996).

In face of the issues of "tendency of outsourcing," besides highlighting the purpose and mission of the STEM curriculum change, there is a need to prepare teachers to develop an endurable change mentality. Fullan (1993) argued for the habits of the mind to cope with "The Complexity of Change" which includes "Change is a journey, not a blueprint" and "Problems are our friends," among other ideas. From that it is envisioned that teachers and schools will regain the moral obligation of offering conducive learning experiences in STEM to students, which will be coupled with the development of schools' and teachers' capacities in their deliberation and undertaking of the curriculum change.

The above efforts can contribute to the offsetting of biases on hot items in STEM by means of informing the decisions on resource procurement, allocation, and utilization in solving daily life problems.

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26 The other two are "STEM Literacy" and "Entrepreneurial Mindset."

5. The challenged effectiveness of supports and enrichments from PDPs

Since there is also no STEM teacher qualification requirement stipulated, the planning and development of these professional training efforts are largely based on the brief recommendation in the Report (CDC, 2016).

It is observed that the EDB relies on the professional development programs (PDPs) to address the building capacity of schools and teachers in STEM implementation. As revealed by the findings of the description research in Section 2.1, they fall short of the expectations of teachers and schools, at least in terms of quantity.

Other channels of capacity building are those organized by tertiary institutions (including but not limited to QTN projects), teachers associations, and resource vendors. From the statistics of events in Group A, most of them were seminars and sharing sessions (40%) organized by associations and vendors, while the much-wanted knowledge enrichment workshops took up only 11.8% of the total number of events. Nearly all of them were one-off events, so inherently they were not significant on enhancing teachers' capacity.

In line with these findings, the frontline teachers interviewed also expressed similar concerns:

- "PDPs are inadequate in number." (Teacher Calvin)
- "PDPs are needed to develop professional knowledge of integration (Teachers Wise & Bruce) and undertaking the curriculum change" (Teacher Wise)

Three issues were observed about the PDPs besides the insufficient quantity.

The first is the reliance on sharing sessions in PDPs. The EDB highlights the guiding principle "Building on strengths" of teachers and schools (CDC, 2016, para. 2.8) to confirm the value of their existing expertise and to encourage them to apply those in the implementation of STEM.

Sharing sessions are usually conducted by schools and teachers with experience in the implementation of STEM. The content is mostly preliminary reports of try-outs that are yet to have robust theory support and are not easily transferable as the practices are school-context-specific.

Secondly, the PDPs are "inappropriate and [there is a] lack of validity and relevance" (Teacher Calvin) so that they cannot specifically address the needs of teachers.

As revealed by the statistics of events organized by associations and vendors, the topics are leaning towards "IT policy related" topics (36.3%) including network security and eLearning, among others. Furthermore, since 2020 the PDP events recorded in Group A have decreased in number and have become less relevant to the need to enhance teachers' readiness to cope with the interdisciplinary integration required in the STEM change.

Interviewed teachers also suggested how subject subculture may influence the validity and relevance of PDPs. They pointed out that the sharing topics in the PDPs incline to the existing knowledge / subject background of the organizers (Teachers Kate & Tim). For example, in a PDP on the topic "Robotics" by a university, the activity suggested to teachers is investigation with a focus on "energy" rather than on essential aspects of robotics including control, mechanism, structure, etc. (Teacher Bruce).

Another example quoted was organized by one of the teacher association. The learning activities presented were solving well-defined problems in the subject context, but not solving authentic daily life problems that are ill-defined (Teacher Bruce). This is a tell-tale illustration of the difference between "STEM for understanding" and "STEM for innovation."

Third is the development of practical capabilities of teachers without DT/ TE background. The required know-how in tools and resource manipulation and capabilities in offering the problem-solving project with tangible outcomes is yet to be developed among teachers, and especially among primary teachers (Teacher Bruce). There are very few PDPs on this area, which results in a severe lack of support mechanisms for undertaking hands-on practice (Teacher Kate).

In discussing the limitations of PD in supporting educational change, Fullan (2008) succinctly stated that:

> "**Professional development (PD)** in workshops and courses is only an input …. Successful growth itself is accomplished when the culture of the school supports **day-to-day learning of teachers engaged in improving** what they do in the classroom and school."

Therefore success lies in the development of a change in leadership (Fullan, 2003) and collegiality (Fullan, 2007) among the school teachers involved, with the basis being a shared vision and purpose to deliver STEM curriculum change. The bottom-up learning community self-help network mentioned previously no doubt can constitute a significant part of the professional learning culture.

At the same time, CAW strives to address the demand in developing teachers' capabilities in offering practical problem-solving with tangible outcomes. From the findings of lesson observations, the CAW undertook the identifying of DT/ STEMaker-project-specific PCK and the common elements of PRA, and the desirable qualities so that teachers' attitudes that can enhance the learning in D&T Projects were extracted (Wan, 2019). This set of elements permeates the efforts of the CAW in the building of a knowledge base for planning and offering DT/ STEMaker projects and the capacity of frontline teachers in the form of PD.

6. *“What will STEM be in the near future?”: A cautionary probing into the momentum of STEM promotion in schools*

There are three observations which point to the case that STEM development in primary and secondary schools is challenging that may affect its momentum as educational change.

Since STEM is yet to have subject status, logically there is the absence of a dedicated senior secondary STEM subject, except for entrusting to subjects in the three KLAs (Teachers Tim & Wise). It is believed that senior secondary school is the best time to develop students’ creativity and innovative capabilities as they are more mature and have more experience of solving daily problems with technological means. However, senior secondary students have to sit the HKDSE Examination after secondary six, the results of which will determine their further study or career path. The studies in the STEM-related subjects will inevitably be examination-oriented. Thus, it is not easy to identify space for “STEM for innovation” type learning. While academically-challenged schools may not be so examination-oriented, proficiency in language hinders students’ abilities to undertake innovative endeavors (Teacher Leon).

As a result, aside from ECAs, school-teams or elite-pull-out types of activities, STEM development has not been smooth at senior secondary in a certain number of schools.

Furthermore, teachers interviewed comment that:

- “Since the Hong Kong society is rather short-sighted, if STEM cannot demonstrate any value or does not have any impact [on nurturing students’ technological and innovative talent], will STEM be here to stay, say, in 5 to 10 years’ time?” (Teacher Wise)
- “It seems that students don’t really understand why they are learning STEM. To them STEM is just something which consists of interesting and friendly stuff to play with.” (Teacher Bruce)

They also point out there are chances that STEM could be crowded out by other emerging tasks. This is because the scene of education is always changing and new demands such as eLearning, among others, keep rolling in.

STEM activities organized by teacher associations and resource vendors also suggest a similar change in priority. In the statistics discussed previously, let us consider the two top-ranking items in the periods 2016-2017 (when STEM was newly introduced) and 2018-now, namely "Coding" and "eLearning." The percentage of events dedicated to "Coding" decreased from 21.9% to 5%, whilst the percentage of "eLearning" increased from 5.5% to 20% between the two periods. The percentage of the categories that include these two items reveals a similar trend.

Table 7 Comparison of trends of events/ activities in STEM social media platform group A

Period	2016-2017	2018-2022	+/-
Coding	28 (21.9%)*	20 (5%)#	-16.8%
eLearning	7 (5.5%)*	73 (18.4%)#	+12.9%
"Coding" Category	30 (23.4%)*	39 (9.8%)#	-13.6%
"IT policy related" Category	25 (19.5%)*	168 (42.3%)#	+22.8%

* Total number of events/ activities counted in the period = 128

Total number of events/ activities counted in the period = 397

<u>Reinvigoration of the STEM vision</u>

Albeit the abovt-mentioned comments, frontline teachers expressed the view that they are still obligated to strive for conducive STEM learning for their students. Refocusing can be a tactic to rediscover the purpose of implementing STEM, be it a "tie-in with new changes [e.g., to complement I&T development in Shenzhen and the Great Bay Area] in order to sustain" (Teacher Bruce), or "utilizing new technologies [appropriate or green technologies, etc.] as a basis, embedding meaning into them in order to enable students to innovate and problem solve with the view to developing transferable skills" (Teachers Calvin & Tim).

<u>On capacity building</u>

The concern about developing teachers' capacity for undertaking the above is to be addressed by the bottom-up movement of learning communities & self-help networks mentioned (teacher Tim) and the CAW's efforts that are based on the "total solution"[27] of STEMaker education (e.g., Wan et al. 2020, Wan & Leung, 2022). These endeavors, inside school and in other schools, constitute a looming volume of experiences and expertise that can contribute to actions and practices sustaining the value of STEM in order to benefit students.

It is encouraging to see teachers are zealous in enhancing their capabilities in the implementation of integrative, hands-on, minds-on "STEM innovation" in their schools. This is evident from the actions of some of them to apply to QEF for more resources to enhance STEM for their students.

Conclusion

In this manuscript the author describes the EDB's positioning of STEM education as curriculum change without a distinct subject status. Teachers have to refer to the curriculum of the three STEM KLAs for content selection and planning of assessment.

The concurrent introduction of imminent education initiatives also affects the course of STEM implementation.

Amid the emergence of demand-driven and popular iconic items, it has been observed that a number of schools opt for the tactics of "resorting to exist-

27 Includes the following components: Vision, Goal, Curriculum organization, Pedagogy and learning experience, Curriculum development support, and Venue recommendation.

ing subject subcultures," "resource-enhancement," and "outsourcing." The "school-oriented" implementation in schools accelerates the side-lining of hands-on practical learning, although it is one of the key features in STEM promotion. This resulted as the difficulty of attaining the goal of nurturing students' innovative capabilities.

In the course of educational change, continuous learning of the leaders and teachers is crucial (Fullan, 2008). Besides, the building of capacity and readiness, the deliberation and laboring on the purpose and vision of the change is also an indispensable component, as it can provide moral purpose (Fullan, 2017) to tackle the challenges which emerge and sustain the undertaking of the change.

While you may not be able to alter the situation, at least you can change your mindset and practices and carry on.

This is exactly the spirit demonstrated by the frontline teachers the author met, that gives him the strength to sustain the endeavor in preparing this manuscript.

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Status and Trends of STEM Education in Ireland

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Abstract

The pace of technological change over the past decade has been unprecedented with significant innovation and development across all facets of how people communicate, work, and live within their daily lives. There is good reason to believe that this trend of technological development will continue, where technologies that we use daily did not exist a decade ago, and in 10 years from now there will be additional technologies that have not yet been conceived. This change has particular implications for STEM careers and the nature of STEM learning as we consider future changes in how we live, work, and learn. This chapter aims to review the relevant policy documents and pertinent literature to highlight the progress in STEM education in Ireland and the direction of future travel within the ecosystem that supports STEM education. The chapter will consider programs from early years education to secondary education. Although, there are many actors in a comprehensive STEM ecosystem, this chapter will focus on the educational programs and how they are conceptualized, implemented, and evaluated. The chapter concludes by acknowledging the progress to date and emphasizing future challenges to ensure that the provision of STEM education in Ireland best serves the learners within to be confident and effective contributors to a global STEM ecosystem.

Keywords: integrated STEM, STEM professional development, STEM performance, STEM ecosystem

Introduction

Advancements in technologies and practices within the disciplines of science, technology, and engineering have disrupted the labor market, creating new emphases on integrated and agile practices, displacing the roles of many jobs as they have previously existed in these sectors. The Irish governmental Department of Enterprise and Trade outlined in their Action Plan for Jobs report that Ireland is host to: nine out of the top 10 global software companies, three out of the top five games publishers, 10 of the top 10 "born on the internet" companies, 15 out of the top 20 medical technologies companies, and nine out of the top 10 pharmaceutical companies (Department of Enterprise Trade and Employment, 2015, p. 7). These statistics highlight how a successful economic future is dependent on Ireland's ability to position itself as a global leader in STEM-related innovation, where the development of a sustainable pipeline of suitably prepared STEM professionals is paramount. Within the engineering sector, the national professional body Engineers Ireland outlined in their submission on the national budget 2022 how STEM skills are vital for the fulfilment of a knowledge-based future for Ireland (Engineers Ireland, 2022). The report also raised the concern of how the number of students undertaking third level engineering and technology programs of study needs to significantly increase, as 94% of engineering employers consider the shortage of experienced engineers to be a significant barrier to growth.

These developments, prospects, and barriers have placed a focused importance on STEM education's role in supporting the development of the national STEM ecosystem. STEM education must be adaptive to stay abreast of the evolving content across the range of STEM subject areas, so that it remains relevant in achieving its goals to prepare its participants for active citizenship in a technologically complex society. It must also ensure that young people who choose to do so are adequately prepared to pursue further studies and careers in STEM, which in turn will provide the required skilled workforce to meet labor market needs through the provision of suitably skilled and adaptable STEM graduates. Supporting learners to fulfil these broader general educational goals and to develop more specific integrated technological skills is now a key challenge for those responsible for STEM education provision at all stages of pre-third level education.

STEM Education Provision

The national STEM education policy statement sets out a goal of providing "*…the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence, and persistence, along with the excitement of collaborative innovation*" (Department of Education and Skills, 2017, p. 12). The scope of the policy statement includes learners from early years education through to second level schooling, and recognizes the importance of engaging young children in the natural developmental exploration that is provided by STEM activity. Engaging with hands-on exploration of physical artefacts and manipulatives can provide a tangible beginning for building more inquisitive, creative, speculative, and critical thinking and behaviors that are the foundations of problem-solving, and innovation and creativity that are central to effective STEM learning. Table 1 presents the program levels, age, and International Standard Classification of Education (ISCED) reference that define the system of education in Ireland.

Table 1 Program level by age and ISCED

Age		Program	ISCED
17/18	Second Level	Senior Cycle	3
16/17			
15/16*			
14/15*		Junior Cycle	2
13/14*			
12/13*			
11/12*	First Level	Primary	1
10/11*			
9/10*			
8/9*			
7/8*			
6/7*			
5/6		Senior Infants	0
4/5		Junior Infants	
3/4	Pre School	Early Years	0

*Compulsory Schooling

Irish preschools are generally privately run organizations, supported by government funding through the Early Childhood Care and Education (ECCE) Scheme, and regulated by the Child and Family state agency. While there is a range of different primary schools, categorized by denominational, multi-denominational, Irish-speaking schools, special schools, and private primary (non-State aided), primary education in Ireland is predominantly state run. However, regardless of these schools being public or private, all primary schools follow the same national curriculum. The post-primary school landscape is comprised of voluntary secondary schools, community schools, and comprehensive schools, which historically have had a more academic focus, while vocational schools and community colleges were more practical and vocational in nature. Increasingly over time, this separation has become less apparent, and the academic/vocational divide has almost merged.

Preschool and Primary

Early years and primary education acknowledges the natural curiosity of young children and supports their holistic development. The integrated curriculum supports an array of opportunities to question and find answers to questions that are relevant and interesting. Building confidence and skill in mathematical thinking is done through applying their learning to everyday situations and to contexts across the curriculum. This integrated approach is supported by an intent to develop "designing and making" skills and "working scientifically," further emphasizing the intrinsic link between mathematics, science, and technology. Young children are encouraged to explore, create, and apply across the curriculum, supporting a fully integrated concept of STEM education.

Junior Cycle and Its Education Reform

The junior cycle (JC) accounts for the initial 3 years of pupils learning in secondary school, and is somewhat more challenged by the idea of a fully integrated STEM concept. The original junior cycle introduced in 1989 brought with it a move towards the holistic development of the young person. The program of study engaged pupils in a breadth of subjects (sometimes as many as 11 different subjects). The approach encouraged pupils to learn in a broad base of contexts and experiences. However, the program was challenged by the assessment practices within. Summative assessment of each subject detracted somewhat from the core objective of personal development and instead was defined by the knowledge acquisition and retention required to be successful in the end of program assessment schedule.

The recently reformed JC is defined by the development of eight key skills (being creative, being literate, being numerate, communicating, managing information, thinking, managing myself, staying well and working with others) (Department of Education and Skills, 2015). The framework supports a common direction across all subjects that has the potential to capture the synergies between subjects. The move from subject syllabi to subject specifications supports a more learner-centered approach to personal development, and affords the teacher more autonomy in the selection, organization, and treatment of relevant knowledge and skills (Department of Education and Skills, 2015). "*To this end, it allows for a certain amount of flexibility and freedom for teachers to facilitate learning in a way that reflects students' own choices, their curiosity, and their creativity. The achievement of learning outcomes should be planned in a way that is active and stimulating*" (NCCA, 2018, p. 9).

The new specifications, particularly within the STEM subjects, make explicit the relevance of discipline knowledge and skills to everyday life. Within Mathematics education the contribution it makes in other subjects is framed with practical examples of links and application in its rationale. The new specifications link prior learning to build confidence in the subject and prepare pupils to meet challenges beyond school life. Learning experiences should be engaging and enjoyable and enable pupils to use their mathematical abilities in creative, innovative, and enterprising ways (NCCA, 2017). "Mathematical proficiency is conceptualised not as a one-dimensional trait but as having five interconnected and interwoven components" (NCCA, 2017, p. 5). These traits are: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (NCCA, 2017).

Within the new Science specification, and with reference to the PISA definition, "*A scientifically literate person is described as someone who is willing to engage in reasoned discourse about science and technology. This requires them to be able to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically*" (NCCA, 2015, p. 9). The epistemological positioning of the new specification is framed in its rationale – "*Science is not just a tidy package of knowledge, nor is it a step-by-step approach to discover*y" (NCCA, 2015, p. 9). The specification highlights that the subject will "*activate intuitive knowledge to generate, explore and refine solutions for solving problems*" (NCCA, 2015, p. 4), deepening pupils' investigative capacity, and their ability to design scientific enquiry and draw justifiable conclusions.

The four Technology (T4) subjects at the junior cycle level in Ireland span a number of technological contexts: Material Technology Wood, Engineering, Applied Technology and Graphics. These subjects are elective and collectively described as the T4 subjects. Although each of the four subjects uniquely mediate the development of technological capability, the development of technological capability is the common purpose. The move to specifications from subject syllabi for the technology subjects is like all other JC subjects and is designed to develop the Key Skills while aligning with the 24 overarching JC statements of learning. Although design was implicit across the previous technological subjects, the new specifications have made designerly activity a central component of technological activity. While the treatment of design varies across the subjects, and the basis for inquiry is bounded by the subject-specific technological contexts, the specifications all similarly support teachers in developing themed learning scenarios, tasks, and projects that address environmental, societal, community, and sustainability challenges.

Senior Cycle

Although the senior cycle (SC) has begun a consultative process to reform the existing program, this chapter will outline the current cycle, with a focus on a future direction of travel. Following on from the junior cycle, the senior cycle has several defined pathways: the established leaving certificate, which sets out to provide a broad and balanced education with the option of specialisms relevant for specific career paths; the Leaving Certificate Applied Programme, which provides a practical and vocationally orientated program built around three key strands: Vocational Preparation, Vocational Education, and General Education; and the Leaving Certificate Vocational Programme, which combines the academic focus with a dynamic focus on enterprise, work, and the community. All SC programs are 2 years in duration and can be preceded by the transition year (TY) program, which is a 1-year program that bridges the personal development from JC to LC and occupies the initial year of the 3-year senior cycle. TY is not an "exam" focused year, but instead a program of broadening experiences and learnings designed by each school to support the holistic development of the pupil.

The senior cycle is also built on a key skills framework, with the interrelationship between communicating, working with others, critical and creative thinking, information processing, and being personally effective, reflecting the overarching approach. STEM is currently not an integrated concept at the senior cycle level. There is an increased number of separate subjects that are classified as STEM (see Table 2) compared to the junior cycle options.

Table 2 Senior cycle STEM subjects

Category	Subject
Science	Agricultural Science Biology Chemistry Physics Physics and Chemistry
Mathematics	Applied Mathematics Mathematics
Technology	Design and Communication Graphics Construction Studies Engineering Technology

Except for Mathematics, the senior cycle STEM subjects are elective and are often selected as a continuation if previously studied at the JC level. For the leaving certificate, individual subject grades are equated to "points" through a Central Applications Office (CAO) that are used to access HE courses of study. Senior cycle subjects are studied at honors and ordinary level, with the maximum points for an honors subject being 100 points and an ordinary subject achieving a maximum of 56 points. To support the development of mathematics, 25 bonus points are awarded if studied at honors level once the candidate achieves a passing grade. Selection of subjects and the level they are studied at is significant when considering the high stakes nature of the Leaving Certificate examinations.

In the senior cycle, the progression from JC science sees the subject area articulated through five subject offerings. The core physics, biology, and chemistry are supplemented by agricultural science, reflecting the national agricultural context and a combined PhysChem subject to increase the breadth of experimental and theoretical exposure for students who may be pursuing a career in science. Within the technology suite of subjects, the subjects of engineering, technology, design and communication graphics, and construction studies follow from the JC equivalents. Excluding design and communication graphics (DCG), the technology subjects are defined by a design and make approach to developing technological capability, and include a practical project as part of the assessment. Although DCG does not employ a make artifact, it has a substantial project element to the assessment, and although its approach is design without make, it is grounded in the potential for manufacture and considers process technology, material selection, and function as critical criteria in the assessment of the design solution.

STEM Agenda and Treatment

STEM education is a significant element of focus for education policymakers internationally, and the prioritization of STEM education in Ireland is apparent from government policy. Although recognized for its importance in contributing to economic competitiveness, social and environmental development and increasing STEM graduates, STEM can still be an elusive construct. STEM captures the combination of science, technology, engineering, and mathematics as a group of related subjects that have gained priority status in much of the policy and curricular discussions in recent years. There are many different definitions and approaches to STEM education, ranging from hierarchical and complementary models to fully integrated models. Other definitions are described by methodology, presenting bilateral, integrated, inter-disciplinary, multi-disciplinary and trans-disciplinary approaches. Reaching a defined consensus on the meaning of the acronym can be difficult, as each manifestation emerges relative to the agenda, situation, and context of the program of learning, and although integrated activity brings a clarity of intent and definition to the concept of STEM literacy and capability, implementation can be a significant challenge when confronted with traditional subject boundaries that serve to segment or "silo" delivery approaches (Granshaw, 2016). The idea of integrated knowledge and skills aligns with real-world manifestations of activity and tasks that call on scientific, technological, and designerly activity to have utility relative to need or agenda.

STEM Education Policy

The Department of Education's STEM Education Policy Statement, published in November 2017, recognizes the need to promote and diversify participation and increase success in STEM (Department of Education and Skills, 2017). It sets out the ambitious agenda of ensuring that young people in Ireland understand and have the capability to employ skills and competences developed through STEM education. This is part of the policy's overarching goal to produce active citizens who can make informed choices about numerous broad elements of their lives, including their future study and career choices. Central to this agenda is the development of STEM initiatives, practices, and actions that are built on the following pillars:

- **Pillar 1**. Nurture learner engagement and participation
- **Pillar 2**. Enhance early years practitioner and teacher capacity
- **Pillar 3**. Support STEM education practice
- **Pillar 4.** Use evidence to support STEM education (STEM Policy Statement, p. 14)

The Department of Education and Skills has also developed guidelines to support STEM education partnerships between schools, school leaders, teachers, and industry from all sectors to align the interests of stakeholders in an ecosystem of STEM development and enhancement. This initiative has led to many STEM education initiatives and partnerships being formed to support STEM learning and activities, including collaborations between Irish primary and secondary level educators and industry partners such as Accenture, Intel, Google, and Ericsson. Case study outlines of these initiatives, amongst others, can be downloaded from https://www.gov.ie/en/publication/756dd-stem-partnerships.

STEM Eco-system

The strategic direction of developing STEM education is a shared vision amongst stakeholders, heavily supported and influenced by governmental incentive and funding. The Irish Government is proactive in developing the STEM strategy with the agenda of providing the best education and training in Europe by 2026 (Department of Education and Skills, 2017). As a result, there is recognition of the need to create an ecosystem that will support the development of active citizens with the required technical capacity. This ecosystem 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. The formal and structured school-based activities are supplemented by the extra-curricular activities consisting of STEM-related activities such as summer STEM camps, workshops, or competitions in non-formal education.

The concept of the global knowledge economy is a key influencing factor in the direction of policy development. The shift from content knowledge to skills and from teaching to learning has significant implications for practice. This presents a utilitarian view of the role of schooling, and a pragmatic function and value placed on knowledge.

Ireland's economic prosperity of recent times has been largely dependent on foreign direct investment (FDI) that has evolved from international recognition of the skilled workforce that our young people make up as graduates of the Irish education system. Ireland's strategy for research and development, science, and technology, namely, "Innovation 2020," sets out the roadmap for achieving the national goals of making Ireland a global innovation leader and driving a strong economy and a better society. This strategy specifically highlights the critical role that STEM education plays in ensuring the continual development of a talent pipeline to support this critical FDI, and an active ecosystem for indigenous tech start-ups.

Participation and Performance

Ireland's *Action Plan for Education 2016-2019* (Department of Education and Skills, 2016) sets out a vision to create a progressive and equitable education and training system that begins by empowering the individual and builds towards the transformation of family, community, and society. It is with this lens that national and international indicators of progress and success are considered, paying particular attention to STEM education. Internationally the key comparative references are the *Trends in International Mathematics and Science Study (TIMSS)* and the *Programme for International Student Assessment (PISA)*. The most recent OECD PISA main study was conducted in Ireland in March 2018. PISA is conducted on a 3-year cycle and is designed to assess the preparedness of 15-year-old students to meet future challenges in their lives, including education (OECD, 2019). Over 600,000 students across 79 countries or economies participated in the 2018 cycle, with Ireland reporting a 100% response rate from the random representative sample of 157 schools selected to participate, with 5,577 students taking part. The major assessment domain in 2018 focused on reading with science and math being assessed as minor domains. Ireland is ranked fourth out of 36 OECD countries and third out of 27 EU countries for reading literacy, which is a useful reference for the standard of education in a more general sense. With the focus on STEM, the minor domains of math and science are directly applicable to the focus of this chapter. The following section will take a macro level view of performance but will not reference the detailed contextual factors that impact performance. This section will give a sense of the performance of Irish pupils on international comparators, particularly in science and math.

Mathematics

The most recent *Trends in International Mathematics and Science Study (TIMSS)* study was conducted in 2019 and recorded the participation of 64 countries (plus an additional 8 benchmarking participants), with 672,000 students taking part. Ireland had participation from 299 schools: 150 primary schools, involving 4,582 Fourth Class pupils, and 149 secondary schools, involving 4,118 Second Year students. The study also included Parents, Principals and math and science Teachers. The findings for Ireland reported that student performance in science and math is very stable, with no significant difference reported since 2015 at either Fourth Class or Second Year. Specifically for math, Irish pupils are statistically about the TIMSS center point when considered with respect to all TIMSS countries. At Fourth Class grade, there are seven countries above, four similar, and 46 below the performance of Irish pupils (Clerkin & Perkins, 2020). Together with Latvia and Lithuania, Ireland is one of the top three EU countries in mathematics at Fourth Class grade.

With no significant gender difference, Irish pupils have a relative strength in the number category, while recording a relative weakness in the measurement and geometry and data subscales. Irish Fourth-Class pupils continue to improve in the cognitive domains of knowing, applying, and reasoning from the 2011 baseline data. However, a relative strength in applying and a relative weakness in reasoning are recorded (Clerkin & Perkins, 2020; Department of Education and Skills, 2020a). The math performance is similar for Second Year pupils, with six countries above, six similar, and 26 below the performance of Irish pupils. Ireland is also a top performing country in the EU TIMSS dataset at this grade. In the Educational Research Centre report on Ireland's TIMSS performance (Clerkin & Perkins, 2020), it is highlighted that there has been a sustained high performance in mathematics since Ireland's initial engagement with the TIMSS program. Within the math content domains, there is relative strength noted in numbers and data and probability, while a relative weakness is noted in algebra and geometry. Within the cognitive domains, relative strengths in knowing and applying and a relative weakness in reasoning are noted (Clerkin & Perkins, 2020).

Like the 2019 TIMSS report, Ireland's performance in the *Programme for International Student Assessment* (PISA) 2018 in mathematics was highly ranked. In the 2018 assessment, Ireland was ranked 16th of the 37 OECD countries, and 21st of the 78 participating countries (OECD, 2019), with an overall mean score significantly higher than the OECD average. The lower than OECD average standard deviation reported for Ireland (90.6) illustrates a narrow spread of achievement across the respective proficiency levels.

Among OECD countries, Ireland has the seventh lowest percentage of low-performing students in mathematics. This percentage of low-performing students in mathematics in Ireland in 2018 exceeds the 10% target set out in the *Action Plan for Education 2016-2019* (Department of Education and Skills, 2016). The percentage of high achievers targeted in the action plan for education was also not reached – where high performance is 2.7% short of the target of 10.9% which was the OECD average in 2018 (McKeown et al., 2019). In Ireland, male and female pupils similarly performed below proficiency level 2, with 15.7% in both cases, while the corresponding OECD average percentages were higher, at 23.9% for males and 24.0% for females. Significantly more male pupils in Ireland (9.9%) compared with females (6.6%) performed at levels 5-6, and the corresponding OECD averages, also significantly differ from one another at 12.3% and 9.5% respectively (Educational Research Centre, 2019; McKeown et al., 2019; OECD, 2019). It appears that there is a narrowing of the gender gap in mathematics, with male mean scores only slightly higher than female scores, but not significantly. Also, the indications are that the Irish education system is comparatively equitable.

Science

Like math, Irish pupil performance in science is above the TIMSS center point and although not as strong as math performance, it is relatively high and stable, with similar performance compared to the 2015 report (Department of Education and Skills, 2020a). In 2019, there were 12 countries above, 12 similar, and 33 below Irish pupil performance at Fourth Class grade (Clerkin & Perkins, 2020). When considered within EU countries, Irish Fourth-Class grade pupils performed below four, similar to eight, and above nine countries. Within the content domains, mean scores in earth science demonstrated a relative strength, while a relative weakness was recorded in physical science (Clerkin & Perkins, 2020). The cognitive domains of knowing and reasoning were recorded as significantly higher when compared to 2015 scores at the Fourth-Class grade (Clerkin & Perkins, 2020). Irish Second Year students also performed significantly above the TIMSS center point, with seven countries above, eight similar, and 23 below the performance of Ireland (Clerkin & Perkins, 2020). Second Year students performed below two, similar to three and above four countries, when compared within the EU cohort. In the content domains, earth science showed as a relative strength, while chemistry and physics were relative weaknesses (Clerkin & Perkins, 2020; Mullis et al., 2020). The applying cognitive domain is aligned with the general performance in science, while there is a relative strength in the reasoning domain and a relative weakness in knowing (Mullis et al., 2020). Overall, the 2019 TIMSS report (Mullis et al., 2020) recorded similar performance of both male and female students, where the differences in Ireland remain small and non-significant.

In the 2018 PISA report, Irish performance in science was also ranked highly. Ireland ranked 17th of 37 OECD countries and 22nd from 78 participating countries in Science (OECD, 2019). Ireland's mean score for science was significantly above the EU average. The standard deviation for Ireland indicated a narrow range of achievement, with only one other country having a standard deviation as low as Ireland. Of the Irish students, 17% performed below Proficiency Level 2, while 5.8% performed at proficiency levels 5-6 (McKeown et al., 2019). Across OECD countries, more males performed lower than females at Level 2 on average. The Irish performance is consistent with this, where more males (18.1%) performed below females (16%) at this level. At Levels 5-6, there was a significant gender difference in performance, with more males (6.8%) achieving at this level than females (4.9%) (Educational Research Centre, 2019; McKeown et al., 2019). Again, this aligns with the OECD average trend in performance at these levels (OECD, 2019).

In terms of low science performers, through the 2018 PISA report, Ireland recorded the eighth lowest percentage of low performers among OECD countries (OECD, 2019). This percentage of low performers in science exceeds the target of 10% as set out in the *Action Plan for Education 2016-2019* (Department of Education and Skills, 2016). A further area where Ireland is not achieving its set targets is that of high achievers. Ireland is ranked 21st among OECD countries for high achievers in science, below the 13% target set out in the Action Plan for Education 2016-2019.

Despite these educational targets not being achieved, there are several promising and notable findings. The significant difference favoring Irish male students in science performance that was found in 2015 has now reduced to a small but insignificant difference in the 2018 dataset (McKeown et al., 2019). However, it should be noted that the mean score of males reduced in the intervening period, while the female performance remained similar. From 1995 to 2015, the performance of male students remained stable in science, while a large mean increase was recorded for female students (Clerkin & Perkins, 2020). The average performance (statistically significant) across the OECD was recorded in favor of males in 2015 and in favor of females in 2018 (OECD, 2019). The 2019 TIMSS report also notes that females outperform males, although this is not statistically different (Mullis et al., 2020).

Technology and Engineering

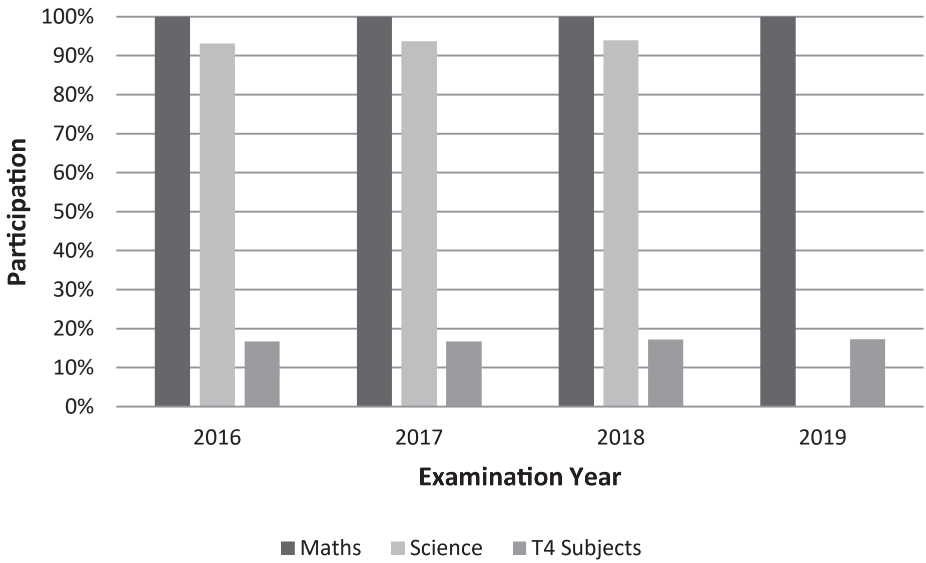
It is very difficult to compare performance in Technology and Engineering by international comparisons, due to the many conceptual and epistemological variations that emerge in the context of origin, treatment, and purpose of these subject areas. The following section will focus on national data to capture trends in performance and participation.

Junior Cycle

Technology and Engineering are categorized within the suite of technology subjects in Ireland for the junior cycle curriculum. The suite of technology subjects consists of applied technology, engineering, wood technology, and graphics, which are commonly referred to as the T4 subjects. In contrast to science and mathematics which have historically been mandatory components of the junior cycle curriculum in Ireland, the T4 subjects are elective, which results in substantial variation in participation rates across the STEM subjects in Ireland. As demonstrated through Figure 1 below, participation in the T4 subjects is significantly lower from 2016 through to 2019. As a means of comparison, in 2019 higher level Junior Certificate mathematics was studied by

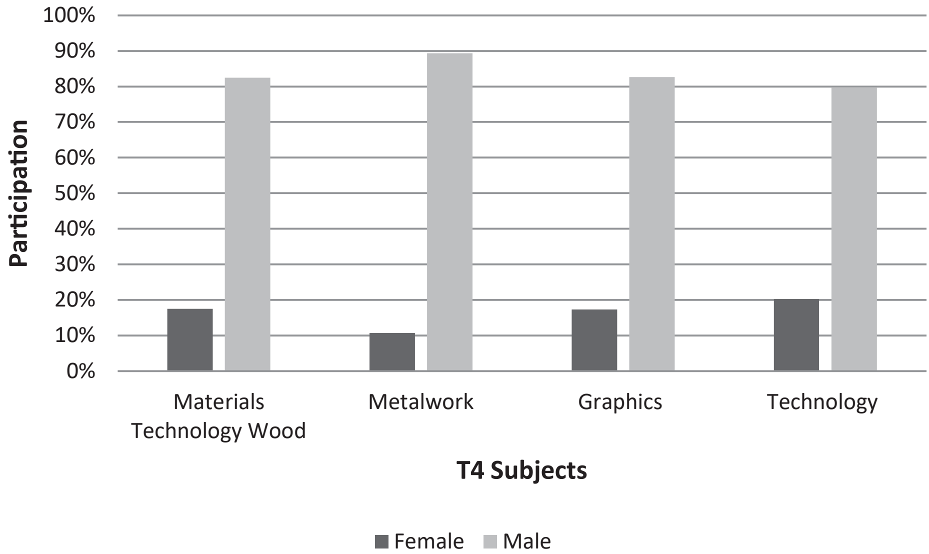
37,433 Irish students, while at the same level wood technology was studied by 14,694, graphics by 9,816, engineering by 6,438, and technology by 3,913. Although the number of students studying the T4 subjects at higher level is quite low with respect to the number of students studying mathematics, this is an increase, albeit small, on the participation rates from previous years. This may be due to an emphasis being placed on increasing participation rates in STEM, which is a key aim of the *STEM education policy statement 2017-2026* (Department of Education and Skills, 2017).

Figure 1 Irish junior certificate STEM participation rates (2016-2019)



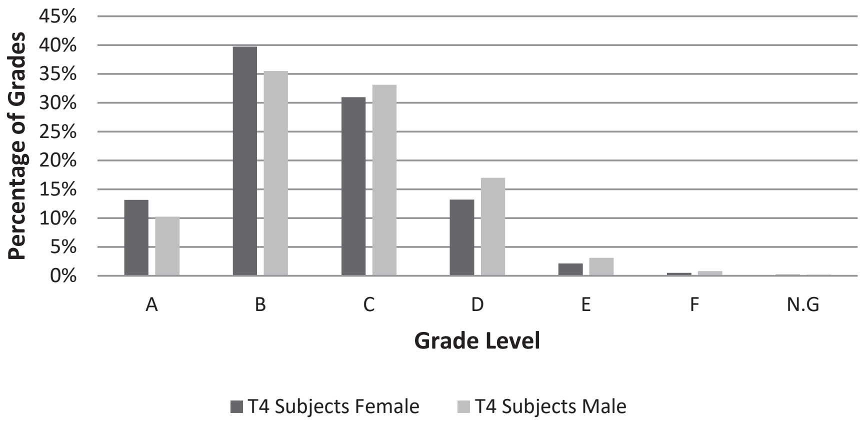
Aside from the overall participation rate differences between the T4 subjects and mathematics and science, there is also a significant difference in the gender participation rates amongst these subjects. Substantially more males pursue studies in the T4 subjects than females, as illustrated in Figure 2 below depicting average participation rates.

Figure 2 Average gender participation rates in the T4 subjects (2016-2019)



In the year 2019, 51.4% of higher level (HL) math participants were female. In stark contrast to this, in the same year and at the same level, 18.7% of wood technology students were female, 20.4% of graphics, 11% of engineering, and 21.5% of technology. Despite these large differences in gender participation rates, the female students that do study the T4 subjects have outperformed males, obtaining a greater percentage of “A” and “B” grades between 2016 and 2019 than males, and a lower percentage of “C,” “D,” and “E” grades (see Figure 3).

Figure 3 Comparison of higher level T4 subject grade distribution between genders (2016-2019)



Considering performance of Irish students in the T4 subjects with respect to performance in math and science (Figures 4 and 5 respectively), the performance trends are quite similar. Of note is that a greater proportion of students studying the T4 subjects obtain "B" grades than those studying science and math. Where performance is compared across genders in these disciplines, the average performance of females in the T4 subjects with respect to males is similar to that seen in science, where males are outperformed by females in the top two levels of achievement. Overall, the average higher-level performance of students at Junior Certificate level in the STEM subjects in Ireland is quite similar.

Figure 4 Comparison of higher-level Math grade distribution between genders (2016-2019)

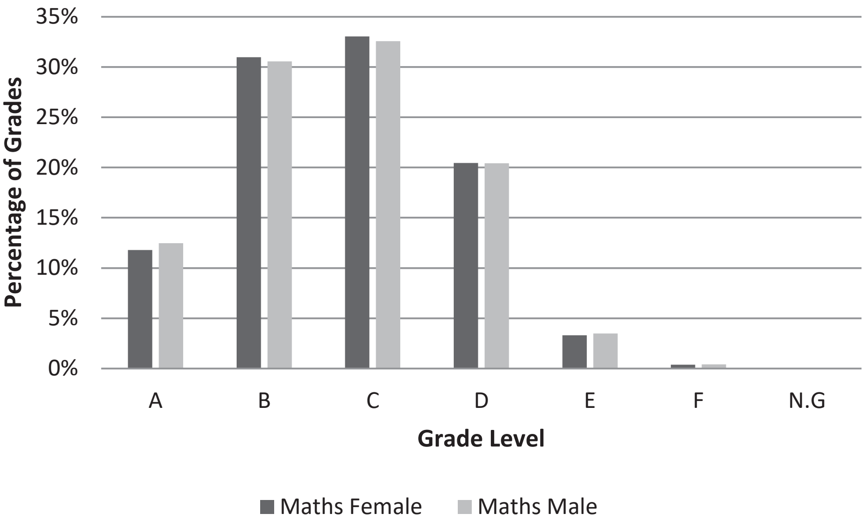
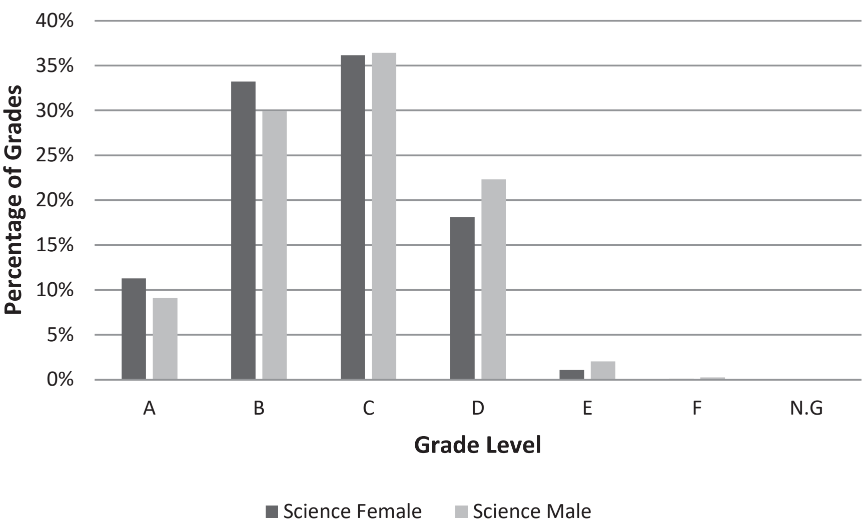


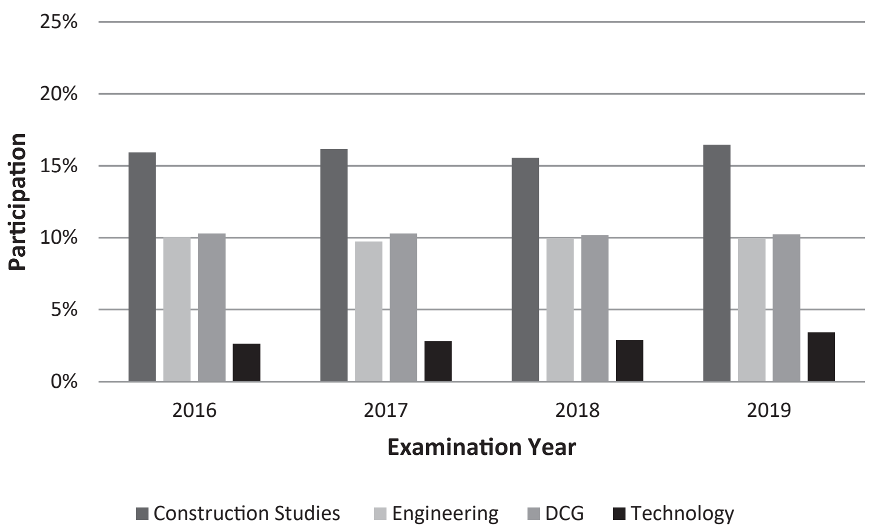
Figure 5 Comparison of higher-level science grade distribution between genders (2016-2019)



Senior Cycle

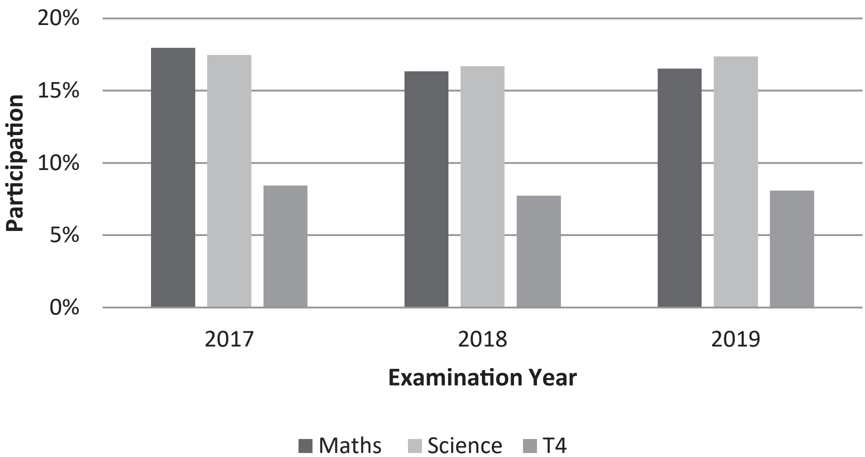
Again, at Leaving Certificate the T4 subjects are optional. Comparing participation rates at this level to participation in a core subject (English), the contrast is stark (see Figure 6). Between 2016 and 2019 participation in T4 subjects was substantially lower than the core subject with less than 20% of learners pursuing construction studies, less than 10% studying engineering, approximately 10% studying DCG, and less than 5% studying technology. This demonstrates a similar trend to the junior cycle level where participation in the T4 subjects is significantly lower than that of science and math, which are core subjects, despite an international emphasis being placed on career opportunities and gaps in this space.

Figure 6 Comparison of optional T4 subjects' participation rates to mandatory subject



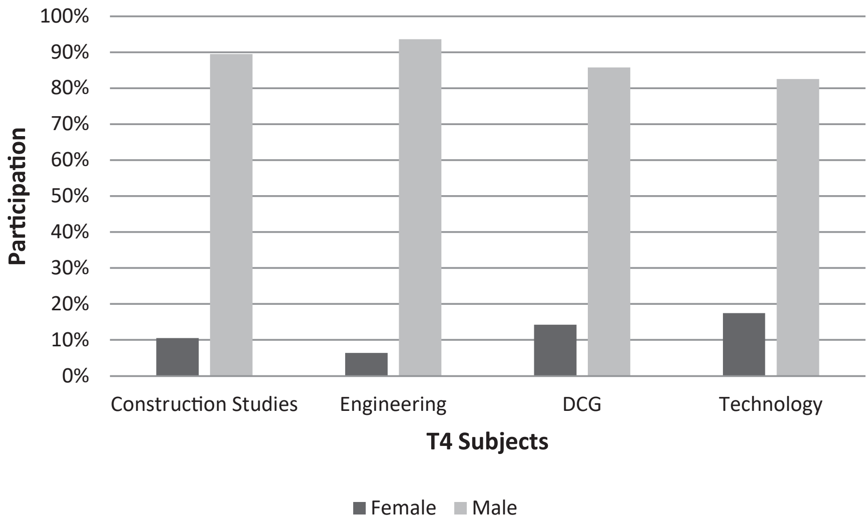
In contrast to the junior cycle curriculum, science subjects are not mandatory at the senior cycle level. Therefore, there is a drop-off in participation levels, particularly within the disciplines of physics and chemistry. Of concern in Ireland is the participation rate of students in higher level Leaving Certificate STEM subjects, as demonstrated in Figure 7. In the period 2017-2019, participation in higher-level math and science was below 20% and participation in the T4 subjects below 10% of the overall number of students completing their Leaving Certificate in these years. Biology accounts for the most significant proportion of science studied at Leaving Certificate level. Removing this, participation in higher-level science also drops to below 10% for Leaving Certificate examinations.

Figure 7 Higher level STEM participation rates (2017-2019)



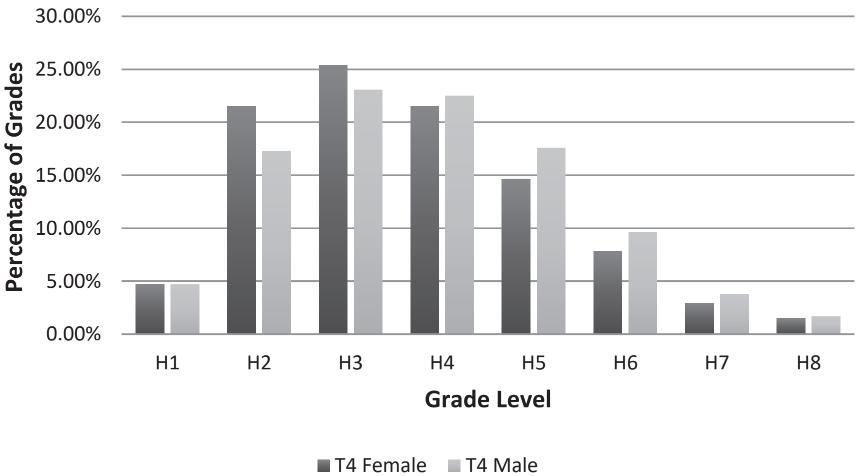
Of additional concern to the previous issue of low higher-level participation rates across the STEM subjects, is the increasing gender gap in participation in Construction Studies and Engineering which are the Leaving Certificate equivalents of materials technology wood and metalwork respectively. However, like the junior cycle (see Figure 2), the gender representation at the senior cycle is concerning across the suite of technology subjects as highlighted in Figure 8.

Figure 8 Average gender participation rates in the T4 subjects (2016-2019)



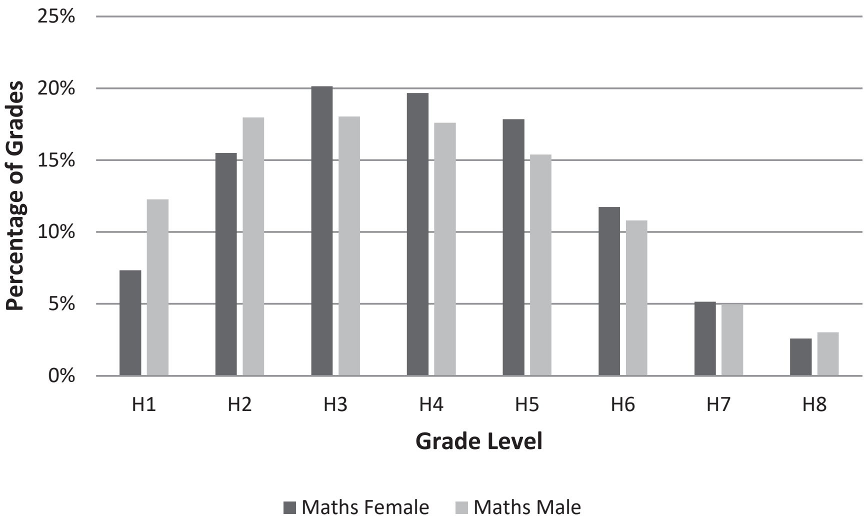
Viewing the average performance across gender in higher-level T4 subjects (Figure 9) does provide a case for optimism. Between 2017 (when the new H grade system was first introduced in Ireland, with grades from H1 to H8, where H1 is the highest and H8 is the lowest) and 2019, Irish females studying T4 subjects obtained more H2's and H3's than their male counterparts and obtained a similar level of H1's, whereas more males obtained grades at the lower end of the grading scale. This demonstrates how females that study the T4 subjects outperform males at the higher end of the grading scale, which is a similar trend to Junior Certificate performance in these subjects. Overall, performance of both male and female students trends towards the higher end of the grading scale for T4 subjects.

Figure 9 Comparison of higher level T4 grade distribution between genders (2017-2019)



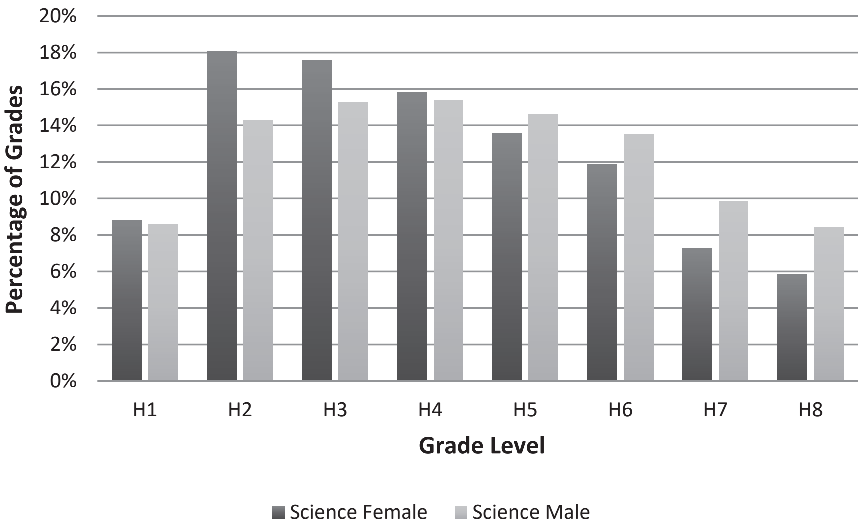
Leaving Certificate higher-level math provides a differing picture of gender performance than that of the T4 subjects (Figure 10). Males outperform females in the two highest grades that can be achieved at this level, whereas more females obtained H3-H7 grades.

Figure 10 Comparison of higher-level math grade distribution between genders (2017-2019)



Performance in the science subjects at Leaving Certificate level (biology, chemistry, physics, agricultural science, and physics and chemistry) is more evenly spread across the grade levels (Figure 11). From a gender perspective, more females obtained H2 to H4 grades, whereas more males obtained H5-H8 grades, with males and females performing similarly at H1 grade. As with all the STEM subjects, it is necessary that efforts are made to improve the performance of students in the higher levels of achievement in the science subjects. A noteworthy priority is to reduce the number of students achieving at the lowest end of the grading scale, which is also a necessary target for junior cycle Science based on the outcomes of the 2018 PISA report.

Figure 11 Comparison of higher-level science grade distribution between genders (2017-2019)



As is evident from the data presented here, in the Irish context, there is work to be done to improve the participation and performance rates of Irish students across STEM education. Efforts need to be made to address the stark under-representation of females in the T4 subject areas which is currently lower than 20% across both junior and senior cycle T4 subjects. Additionally, it is apparent that an emphasis needs to be placed on increasing the number of students studying the subjects at higher level in the junior and senior cycles to meet Ireland's STEM performance and participation targets.

Learnings from Performance Indicators

Through TIMSS 2019 and PISA 2018 reports, Irish students are noted to perform highly with respect to other OECD and EU countries in the areas of science and math (Clerkin & Perkins, 2020; OECD, 2019). Due to the lack of internationally comparable data for technology and engineering at Secondary

School level, it is not possible to determine where these students' performance is positioned internationally. Although Ireland is performing highly in STEM with respect to other OECD and EU countries, the number of low performers in science and math subjects exceeds the target of 10% set out through the Action Plan for Education 2016-2019 (Department of Education and Skills, 2016). The number of high performers in science is also below the 13% target outlined through this same plan. To address these shortfalls in performance targets in these subject areas, school self-evaluation (SSE) processes should be used to develop and refine practice in mathematics and science. Schools should continue to pay particular attention to the learning needs of low achievers and high achievers – setting discrete targets to improve performance in the strands of data, shape and space & measuring and the skills of applying and reasoning in mathematics and the physical sciences.

Learner Progression through STEM Education

There is also a challenge in STEM education to increase the number of learners choosing STEM subjects at the post-primary level, those progressing to STEM pathways in Further and Higher education, and those taking up careers in STEM. Participation at the post-primary junior cycle level increased marginally in the 2016-2018 period (Department of Education and Skills, 2019). Concerningly, at the senior cycle level, there has been an overall decrease in participation rates in the suite of STEM subjects offered for Leaving Certificate (see Table 2) in the 2016-2018 period except for marginal increases for chemistry and technology (Department of Education and Skills, 2019). Progression to STEM-related third level programs of study in this time has remained relatively stable; however, lack of progression to year 2 of STEM courses remains a significant issue to be addressed with non-progression rates between 7%-48% across Further and Higher education courses in the 2015/2016 year (Department of Education and Skills, 2019). Despite these issues, Ireland produced either the highest or second highest proportion of graduates (per 1,000 graduates) in STEM in the EU between 2014 and 2017, which is significantly above the average in the EU (Lawlor & Burke, 2020). However, this is insufficient to keep pace with Ireland's STEM skills demand, with skills shortages identified within all STEM areas (McNaboe et al., 2017).

Trends and Issues in STEM Education

As previously outlined, a national goal has been set out whereby "*Ireland will be internationally recognized as 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*" (Department of Education and Skills, 2017, p. 12). This ambition calls for systematic improvement throughout the continuum of education across the stakeholder dimensions of the learners, teachers, schools, and society. Hence, there are six trends and five issues in STEM education in Ireland as follows:

Trend 1: Emphasizing holistic competency development

There are various areas that need to be emphasized throughout the Irish education system to provide high quality STEM learning experiences to all students so they can participate, influence, and be successful in a changing world. Of particular importance is the issue of striking the balance of essential discipline and technical knowledge and skills, but also developing fundamental transversal and cognitive skills for success in these disciplines.

STEM subjects have generally been quite prescriptive in the past in terms of the content that learners are required to know and understand to progress. However, over the last number of years in tandem with the new junior cycle and planned senior cycle reforms, an increasing emphasis has been placed on supporting learners in developing more holistically and developing fundamental transversal and cognitive skills which will transcend subject areas. With respect to STEM disciplines, problem solving, innovation, and creativity are noted as key transversal skills to be developed. A core cognitive skill relating to success in STEM and other key transversal skills is that of spatial ability. Spatial ability is an individual's capacity to mentally manipulate visual imagery to solve problems (Schneider & McGrew, 2018). Through a significant body of research, spatial ability has been evidenced as a predictor of success in STEM disciplines where students with higher levels of spatial ability are more likely to obtain higher education degrees (Bachelors, Masters, and PhDs) than those with lower levels of spatial ability (Wai et al., 2009). Spatial ability level is evidenced to relate to more holistic problem-solving approaches and more innovative and creative problem-solving solutions (Kell & Lubinski, 2013). Spatial ability can also support reasoning capabilities which were noted as a relative weakness for Irish students in math through the 2019 TIMSS report.

In addition to being a predictor of success in key skill areas and in STEM more generally, spatial ability is also attributed to the underrepresentation of cohorts in STEM subjects. Gender differences in favor of males have been noted throughout spatial ability research (Sorby et al., 2013). Spatial skill levels of learners from lower socioeconomic backgrounds and ethnic minorities are also noted to be lower than those from higher socioeconomic backgrounds and ethnic majorities for both males and females (Casey et al., 2011). Research has noted that a lack of access/facilities/time engaging with resources which can support spatial skills development from a young age has influenced the representation of these cohorts in STEM.

Trend 2: Increasing representation in STEM

As a core agenda to be addressed in Irish STEM education is that of representation and providing a high-quality STEM education for all learners, it is necessary that all learners are in fact represented in these subject areas. Representation in Irish STEM education may be practically achieved through the purposeful development of the core cognitive skill of spatial ability. Currently, there is no direct intervention for developing the spatial skills of Irish students implemented across curricula and school levels. To have an impact on participation and representation levels in STEM, as well as improving reasoning capabilities to address TIMSS weaknesses, it is necessary for efforts to be made to strategically integrate spatial skills development throughout STEM at all levels of education to influence learner performance and progression rates. Irish STEM researchers are currently leading a European Union Horizon 2020 funded international collaboration, SellSTEM – Spatially Enhanced Learning Linked to STEM (https://sellstem.eu/). The project aims to examine spatial abilities in relation to performance and career choice and to examine the interaction through gender, region, and socioeconomic status. The research will not only contribute to further understanding of the role of spatial abilities in STEM but also inform approaches for developing spatial skills that can be enacted by STEM educators. This will be explored further in the following subsection.

Trend 3: Enhancing provision of inclusive and integrated STEM environments

Teachers are central to Ireland achieving its ambitious targets of being recognized as providing the highest quality STEM education experience. Teachers are at the core of ensuring that an inclusive environment nurturing curiosity, inquiry, confidence, persistence, and excitement is provided to learners to allow them to flourish in STEM. To facilitate educators in achieving this it is necessary that they have support in building a professional STEM knowledge base including discipline-based knowledge, methods, and processes. This should include practitioners from across early years education to secondary teachers for the promotion of STEM education. Integrating the STEM policy statement into initial teacher education will help develop an excellent STEM knowledge base and continuing development of pedagogical content knowledge in and across the STEM subjects. This can support the development of effective and engaging teaching, learning, and assessment approaches for STEM where practitioners can provide collaborative environments to foster learners' curiosity, inquiry, resilience, and creativity (Department of Education and Skills, 2017, p. 13).

From a long-term perspective, initial teacher education and early learning education providers should review their program offerings and ensure that they incorporate STEM pedagogies and learning environments. Development of learning environments plays a significant part in influencing an integrated approach to STEM learning and the identity of STEM as an important construct. The environment plays a critical role in supporting the design and make functions of an integrated STEM experience, and can facilitate the utility of knowledge and skills that transverse the creative and innovative endeavors of the learner. The role of designerly actions and the treatment of design activity is critical in ensuring meaningful directions of travel in unpacking the (re)solutions to defined challenges. Immersing future practitioners in these experiences throughout their own learning experience will provide them with experiences to draw upon for future enactment in their own practices. Further iterations of Cosán[1] could integrate teacher learning in STEM and advancing awareness and understanding of contemporary pedagogies to facilitate the development of learners' STEM knowledge and skills. Future and current educators should gain experience in the use of digital technologies and the pedagogical and motivational advantages of employing these technologies in STEM education (Inspectorate Evaluation Support and Research Unit, 2019). The use of these technologies should be encouraged to support learners in articulating

1 Cosán is the Framework for Teachers' professional learning and seek to foster a culture of professional learning, based on engagement in their own learning for the benefit of their student.

features of quality and in developing efficient ways of realizing concepts, prototypes, and functional models of both products and systems.

Trend 4: Promoting connected STEM learning experiences

In the context of STEM, the approach to defining key skills as a means of directing curricular activity is a useful framework to support more connected experiences across subjects. This approach has significant potential in reconceptualizing not only subject boundaries but also an integrated STEM education. The move away from content-defined syllabi to subject specifications affords the teacher greater autonomy around the contextual treatment of content knowledge. Biesta et al. (2015) recognized the importance of such a shift in creating increased teacher agency and moving from didactics to the facilitation of student learning. However, increased agency must be supported with appropriate professional development. Su Ling et al. (2020), in their case study exploring the implementation of integrated STEM education, highlighted the lack of integrated STEM pedagogical content knowledge and the need to support teachers in developing effective methodologies for an integrated approach. The role of the teacher is crucial in integrating STEM concepts and skills, through authentic and engaging tasks. Specific professional development needed to support a coherent approach to integrated STEM must maintain the centrality of the learners' needs in navigating their speculative inquiry with the necessary knowledge and skills to be successful in meaning making. To reconceptualize the paradigm of subjects would enable the capacity to transverse disciplines in pursuit of STEM challenges that are engaging, relevant, and authentic, which require real-world connectedness such as societal or industrial contexts.

Connecting schools, teachers, and universities with STEM industry can provide an important link between how STEM learning is conceptualized and practiced, and can ensure that learning remains contemporary and relevant, while also being engaging and tangible. In the case of initial teacher education, the STInt program at DCU (Hurley et al., 2021) is a useful example of how pre-service teachers can connect with STEM industries to gain skills and experience that can inform and refine their conception of STEM activity. The program has the primary goal of equipping student teachers with experiences and knowledge of STEM in the workplace so they can draw upon these unique experiences and transfer their knowledge and skills gained to pupils in their classrooms and colleague teachers alike. Some of the key impacts of this program have been the pre-service teachers' increase in their awareness of STEM careers in industry and the relevance of STEM to real-world application cases (Hurley et al., 2021). During their industry internships, pre-service teachers get first-hand experience of the innovations, technologies, and services that encapsulate and demonstrate STEM capability. This insight can play a critical role as a point of reference for future learning design and pedagogical decision making.

Trend 5: Increasing awareness of pedagogies to compliment STEM learning

At a more nuanced level, it is also necessary to support STEM education practitioners in understanding and enacting approaches to develop core skills. There is a need to ensure that we do not focus on content at the expense of skill development. For example, as previously mentioned, spatial skills are a key skill for success in STEM and underpin problem solving, creativity, innovation, and reasoning which are all key competencies for development in STEM education. Spatial skills can be developed through direct interventions which include term-long training courses (Sorby & Baartmans, 2000). These training courses have been used at upper post-primary level and in higher education to promote the development of spatial skills. To have a longitudinal impact on participation in STEM it is important that spatial skills development is also emphasized from early years level throughout education progression. Indirect methods of developing spatial skills include the integration of spatial language, imagery, and activities into education (Uttal et al., 2013). This includes the use of diagrams, encouraging an emphasis on imagination and visualization, sketching and play such as with LEGO blocks and shapes. Digital technologies have also previously been used for direct and indirect development of spatial skills (Uttal et al., 2013). This has included video gaming and interaction with virtual reality and augmented reality environments. Mechanisms for spatial skills training could therefore be integrated into CPD activities, ITE, and early learner education in tandem with digital technologies to gain from the advantages that these technologies can offer in terms of STEM knowledge and skills development.

Advancing educators' STEM knowledge and skills base along with awareness of pedagogies and technologies to compliment learning can support teachers in developing their confidence and capacity to identify opportunities for STEM learning across the curriculum (Inspectorate Evaluation Support and Research Unit, 2019). It can also contribute to the implementation of appropriate experiential learning approaches and strategies including to develop mathematical and scientific skills and grow understanding of the meaning and use of STEM language in a playful, meaningful, and enjoyable way. Gaining a holistic perspective of STEM education across education levels could also help teachers sustain learning during transitions from primary to post-primary and post-primary to higher education to support a greater focus on the continuity of learning and pedagogy in STEM. Ensuring a balance of knowledge and skills development in STEM education is of particular interest in the context of assessment and ensuring that assessment methodologies are appropriately aligned with the emphasis of respective programs of study and the goals of STEM education. Having explored the necessary focuses required on learners and teachers for STEM education in Ireland, it is pertinent to examine the focus required on a whole school level to promote STEM education and attainment.

Trend 6: Incorporating STEM policy into school assessment to achieve targets

To ensure that the ambitions and targets of STEM policy are enacted in education practice, it is essential that these policies are included in schools' self-evaluation reports, and should be linked to the key indicators of success. Schools can contribute to addressing STEM targets through evaluation of their culture, policies, practices, and performance. As set out in the national policy statement, such periodic reviews would capture the progress towards the Irish STEM education agenda (Department of Education and Skills, 2017). Evaluation in this manner could support the further embedding of STEM education policy across education and therefore the alignment of education with the goals of the national STEM policy. This would address the current need to increase awareness of the national STEM agenda. School self-evaluation could be promoted through a national accredited school-based STEM program which would give structure and provide recognition of school achievements in STEM on a national level (Department of Education and Skills & Inspectorate, 2020). It is intended that evidence obtained through national (i.e., state examinations) and school assessments will be used to improve STEM education practice where the Department of Education's Inspectorate will regularly report on STEM education quality (Department of Education and Skills, 2017).

On a broader societal level, there is a need to ensure that Irish citizens are equipped with the relevant STEM knowledge and skills to engage in an ever-changing world. Achieving this requires an emphasis to be placed on Ireland becoming a leader in Europe in the education of a highly qualified and diverse STEM workforce. It is necessary that through our society and across all levels of education that Ireland cultivates a world standard STEM ecosystem for young people and in the professional development of educators and upskilling the existing STEM workforce as and where required. Ireland must aim to increase their STEM performance in cross country rankings and to increase participation in STEM studies and careers (Department of Education and Skills, 2017, p. 14).

The STEM policy statement sets out several key performance indicators of varying natures and ambition levels. These include increasing participation in Leaving Certificate (senior cycle) chemistry, physics, technology, and engineering by 20%. A 20% increase is sought in extra-curricular STEM activities in schools in every region for the promotion of STEM across all school types. The policy also aims to increase female participation in STEM subjects by 40%. To have such an impact on female participation it is crucial that there is increased visibility of female STEM role models in Irish society. Throughout the last number of years, the Women in STEM (WiSTEM) movement has been increasing in Ireland. The movement is supported and promoted across various Irish universities with their aim being to support, help, encourage, and champion women in STEM through team projects, industry mentors, student awards, and carrying out research to understand the barriers that women face in STEM (e.g., https://www.ul.ie/soedu/projects/wistem). Advancement, increased participation, and awareness of the movement in Ireland can support an increase in female participation in STEM over time. There is also an emphasis being placed on Irish education policy to increase the representation of vulnerable learners, other under-represented groups and the most marginalized in higher STEM education (Department of Further and Higher Education Research, Innovation and Science, 2020). It is therefore important that a similar movement to that of WiSTEM is supported in Irish society to increase the visibility of role models for under-represented cohorts in STEM and awareness of the challenges that these individuals face in pursuing STEM studies and careers. Promisingly for STEM representation, increasing awareness and support in this area is outlined as a high-level action to be achieved through the STEM education policy for 2017-2026 (Department of Education and Skills, 2017).

Issue 1. Accessibility and achievement for STEM learners need to increase

Further to balancing the development of learners' knowledge and skills, there is a broader emphasis required in Irish education to increase the accessibility and achievement in STEM of learners from educationally disadvantaged schools and learners with special educational needs to enable them "*to participate, influence and succeed in a changing world*" (Department of Education and Skills, 2017, p. 13). Educationally disadvantaged schools are referred to as DEIS schools. The DEIS program is focused on targeting additional resources with the goal being to ensure that all learners, irrespective of background, have an equal opportunity to achieve their potential. Currently, DEIS school retention rates of learners to Leaving Certificate level of post-primary school are below those of non-DEIS schools. Between 2016 and 2020, a significant gap has remained in the number of learners pursuing higher education. For instance, in 2020 71.3% of non-DEIS learners transitioned to higher education, whereas 46.7% of DEIS learners pursued higher education (Department of Education and Skills, 2021). Learners from DEIS schools are also twice as likely not to progress into the second year of higher education programs than those from fee paying schools. To address this disparity, and specifically in the context of STEM, it is necessary that these learners have access to excellent STEM education and career information to manifest positive attitudes towards STEM (Department of Education and Skills, 2017). Establishing excellent STEM education for all learners requires additional access to resources to support learning. More broadly across all schools, there is a need for continuing professional development (CPD) for teachers to advance STEM knowledge and awareness of pedagogies to scaffold STEM learning.

Issue 2: The critical role of STEM teachers has not drawn enough attention

The teaching profession in Ireland remains a high-status profession (Irish National Teachers' Organisation, 2018) and is seen by society as an important profession. The National Teaching Council as the professional standards body for the teaching profession, promotes and regulates professional standards in teaching. The scope of their remit spans the continuum of teacher education, from entry and initial teacher education to in-service teachers' learning and professional development. The Council has defined standards and frameworks to support teacher learning within; Céim: the standards for pre-service Initial Teacher Education (The Teaching Council, 2020), Droichead: the integrated professional induction framework (The Teaching Council, 2017) and Cosán: the Framework for Teachers' learning and in-service professional development (The Teaching Council, 2016). The structures and supports are in place to ensure the highest quality of teaching and learning in Irish schools. This structure is an important feature of the education system's capacity to align teaching and learning with current and emerging policy directions.

Initial teacher education plays a significant role in developing teacher identity and developing professional capacities to support professional practice. There are two primary routes to qualifying as a primary or post-primary teacher in Ireland: the consecutive initial teacher education programs or concurrent teacher education degree programs. The consecutive model requires a person to hold an honors bachelor's degree in an area relevant to the subject they wish to teach and to complete a professional master's in education (PME) degree. A PME is a 2-year full time program of study that typically focuses on professional, foundational, pedagogical, and school-based learning. The concurrent model utilizes bespoke designed programs that integrate the subject specialist modules with foundational, professional, pedagogical, and school-based learning. Concurrent degrees account for a smaller proportion of graduate teachers and are predominantly teachers of practical subjects. Typically, student teachers are qualified to teach two subject disciplines; for example, students can select two from chemistry, physics, or mathematics, while technology and engineering are usually combined within the four technological subjects and currently cannot be studied with either science or mathematics.

Issue 3: Lack of an integrated STEM approach

The ambition in Ireland is that STEM education will be an integral part of schooling at all levels (Department of Education and Skills, 2017). This will include STEM being integrated and its importance recognized within the school culture, policies, and practices.

Very positive evidence demonstrates the integrated nature of STEM learning in early years education, and notably this includes learning through STEM methodologies and not just STEM knowledge. At the primary and especially post-primary levels where subject boundaries are defined, work needs to be done to develop a more integrated approach to STEM learning and to achieve multidisciplinary and interdisciplinary approaches to problem solving. At post-primary level, isolated subject definitions need to be challenged in favor of a more integrated STEM learning experience and be developed as an integral part of everyday practice. While subject definitions remain, Irish schools at all levels can look to achieve integrated STEM education by addressing several key areas including STEM accessibility, promotion and awareness, spaces, increasing representation of a diverse range of learners within STEM classes, and school self-evaluation with respect to STEM agendas.

Issue 4: A lack of flexibility in STEM subject offerings

Reflecting on the accessibility of STEM education in Ireland requires consideration of the culture and offering of these subjects at a school level. Focusing initially on the T4 subjects, these subjects are not offered in all schools throughout the country. This can be due to a lack of space, funding, and availability of teaching staff and other resources. In some instances, schools may only provide one of the T4 subjects which can subsequently have a long-term impact on accessibility to a broader STEM education experience. This accessibility can be further reduced through the learners' subject choices. As previously noted, the post-primary school system in Ireland has mandatory subjects, which are English, Irish, and math at the senior cycle, and elective subjects, which include the suite of technology subjects at the junior and senior cycles level and science at the senior cycle. At the beginning of both cycles, learners are required to select various optional subjects from a "line" system where a series of subjects are listed across multiple lines and the learner is required to select only one subject from each line. This may include offering STEM subjects on the same lines as one another or on the same line as languages (as an example). This may at first glance seem insignificant; however, at 5th year level (age 16/17), learners are required to select the subjects that they will study for their Leaving Certificate, which will determine what courses they can apply for to pursue further or higher education. As studying a language is often a requirement for entry into many university courses in Ireland, the positioning of STEM subjects on the same subject choice lines as languages (for example) can present a barrier to learners pursuing STEM subjects at the senior cycle and can therefore have a negative impact on their opportunities to pursue future STEM careers. To address the ambitions set out through Ireland's STEM education policy, and to increase participation in STEM subjects at the senior cycle, it is necessary that subject offerings are carefully considered at school level to provide learners with greater opportunities to pursue studies and careers in this area.

Issue 5: Gender stereotyping, curriculum accessibility, and resourcing of STEM education are three major challenges in STEM culture

Further to the accessibility to STEM subjects is the requirement for schools to develop a whole school culture and environment that promotes learners' interest and participation in STEM. There are various non-formal STEM education initiatives that Irish education providers can engage with to promote STEM and a culture of scientific and technological innovation. These include:

- Discover Primary Science and Maths Program - a Science Foundation Ireland program aimed at increasing STEM interest among students, teachers, and the public
- British Telecommunications (BT) Young Scientist and Technology Exhibition – a competition committed to cultivating and nurturing the talent of future scientists and engineers
- SciFest – a STEM fair with the mission to ensure all second-level students can develop critical STEM skillsets
- Maths Circles – an initiative aimed at developing math capability through enjoyment of investigation and discovery.

Some initiatives go beyond basic STEM problems and look to consider societal issues and ethical responsibilities more broadly in STEM practices. This provides learners with an opportunity to develop a more holistic perspective of STEM implications and future career directions through their own work and that of their peers. Engaging with these initiatives there is an opportunity for schools to connect learners with external partners, including industry, public sector bodies and research institutes to further explore their STEM solutions, to see STEM in practice, and to gain understanding and experiences to contribute to their own identity as STEM learners. As these external partners are stakeholders in STEM, they can support schools in communicating the importance of STEM education to their students. Such a holistic approach to STEM promotion can support schools in addressing the Irish STEM education agenda of developing learners that are active citizens that can make informed decisions about a broad range of elements in their lives (Department of Education and Skills, 2017).

To compliment engagement with STEM education initiatives, schools should be supported in reimagining creative spaces for STEM teaching and learning. Infrastructure should be developed and resourced accordingly, where external partners could contribute to this area in terms of identifying appropriate spaces or redesigning existing ones to create a space that will foster the creative endeavor and experiences of the learner. It is pivotal that learner creativity in STEM should not be limited due to a lack of available resources. This is a significant issue, particularly in DEIS schools. An emphasis should be placed on supporting these schools in obtaining resources to nurture the STEM experience and learning with a view to improving DEIS school performance in STEM and representation in higher education which is an important component of Ireland's education strategy for post-primary and higher education (Department of Education and Skills, 2011, 2020b). As previously outlined, representation is an important issue to be addressed in Irish STEM education as set out through the STEM education policy. In the technology-based subjects there is a high differential in female and male participation. A focus must be placed in schools on increasing female participation in these subjects. This is recognized as a multi-faceted issue that requires a wide-ranging solution. Consideration must be given to gender stereotyping, curriculum accessibility (explaining what the subjects entail and subject choice), and resourcing of STEM education. Addressing representation in STEM is a long-term mission which should be focused on from early years to higher education to achieve diverse representation in STEM which can contribute to solving complex problems affecting a diverse population.

Conclusion

The importance of STEM education is well recognized and supported by policy and funding decisions. It is also apparent that Ireland has a well-developed STEM ecosystem that will support the evolution of STEM education. From formal provision to informal activities, there is a shared agenda across all stakeholders to increase STEM participation and performance.

Acknowledging the centrality of teacher knowledge and skill within the revised consensus model of PCK (Carlson & Daehler, 2019), and the inter/trans/multi-disciplinary manifestations of STEM, professional development is identified as a significant focus. There is a need to consider professional development across the various program levels. Could a STEM framework be conceived to represent the continuum of capability from multi-disciplinary learning that broadens the perspective of knowledge types, modelling, and problem solving? Then transitioning to a more focused trans-disciplinary approach begins the journey to full integration considered as the pinnacle of capability where agency, efficacy, and impact are central to the individual or group learning. This becomes the target for secondary education.

The importance of math and science is apparent; however, a rebalancing to place more emphasis on technology and engineering can bring with it tangible, practical examples of the utility of science and math. Although technology education research is a relatively younger educational research area, there are useful insights emerging from technology education that can support a purposeful integration of STEM. Spendlove (2012) highlights that one of the advantages of design and technology education is that it is "bereft of explicitly defined content knowledge" and as a result, knowledge is often "borrowed" from other disciplines. This is an important feature for full integration as decisions in relation to treatment and context are left with the teacher. Barlex (2014) highlighted that design and technology education is characterized by the fact that there is no single correct answer. Embracing designerly activity could form a critical medium to support the agenda of integration and broaden the conception of STEM activity that could support broader participation. Kimbell (2011) also acknowledges that students can be successful in design and technology in multiple different ways. Students need to be supported in a critical and speculative approach to non-determinist outputs that are appropriate for integrated STEM learning activity.

Finally, recognition for the significant work done to date has created a solid foundation for the development of a comprehensive STEM learning experience at all levels from Primary to Secondary education. Building on the integrated nature of early years and primary experiences is now the goal of secondary school activities to offer a continuum of truly integrated STEM learning to support future success and diverse participation in STEM.

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Status and Trends of STEM Education in Singapore

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Abstract

This chapter describes the status and role of STEM education in the island state of Singapore. In Singapore, STEM education has the important function of ensuring the continuity of a scientifically and technically competent workforce to sustain its robust economy. The economic growth of Singapore is largely reliant on STEM-related industrial sectors such as electronics, biomedical science, and precision engineering. Currently, through the Ministry of Education (specifically the Academy of Singapore Teachers, the Curriculum Planning and Development Division, and the Science Centre, Singapore), the National Institute of Education (specifically meriSTEM@NIE), and two specialized STEM schools, STEM applied learning programs are voluntarily adopted by primary and secondary schools. In the last three years, Singapore has embarked on efforts to renew its STEM education ecosystem. The Ministry of Education in Singapore has spared no effort to ensure that STEM education policies remain current and competitive by setting up a special committee to look into the K-12 STEM education trajectory. For instance, starting in 2020, there has been a systematic effort to ensure that all primary school students acquire a basic level of coding competency by extending to every child a compulsory coding enrichment program. Besides K-12 STEM education, tertiary education providers in Singapore are also continually reviewing their STEM curriculum to ensure alignment with and continuation of learning experiences and industrial relevance. Support for STEM education in the form of resource and expertise input from industries, non-government organizations, and informal learning organizations adds authenticity and diversity to STEM practices in K-12 schools. Informal/non-formal STEM learning is also flourishing in Singapore with enrichment centers and coding schools offering courses and holiday camps. Through the concerted effort of different parties, STEM education in Singapore is moving forward in a rapid manner.

Keywords: knowledge-based economy, integrated STEM, spiral curriculum

Introduction

Background of Singapore

Singapore is an island city with a land area of 728.3 km^2, and a population of 5.68 million as of 2020. As one of the most densely populated countries in the world, Singapore has a thriving economy that relies largely on knowledge and technology. The gross domestic product of the country in 2020 was USD 340 billion. With no significant natural resources, Singapore relies largely on its human resources. As such, education plays a significant role in Singapore's economic growth. Singapore's economy thrives as a business hub with manufacturing (20-25% of its annual GDP) as one of the essential economic pillars. The industrial sectors propelling the growth include electronics, chemicals, biomedical sciences, precision engineering, logistics, and transport engineering (Hawksford, 2017). The reliance on knowledge and competencies from the fields of Science, Technology, Engineering, and Mathematics (STEM) for economic growth has resulted in an emphasis on STEM education to ensure a pipeline of relevant expertise for Singapore. Singapore's political leaders have also emphasized the need for STEM education. For example, Lee (2015) reported that Prime Minister Lee Hsien Loong reminded universities that developing STEM competencies is fundamental to maintaining the economic growth of Singapore. Emeritus Senior Minister Goh Chok Tong (2017) mentioned in his keynote address at *ASEAN@50: In Retrospect Seminar 2017* that "[w]e must push bright young students towards STEM." At the core of STEM education are new ideas, inquiry, and innovation that are likely to be instrumental in other fields of study and hence ought to be encouraged.

Globally, the advent of the fourth industrial revolution has heightened the impact on human life and communities of digitization and technology. Their impact on and transformation of the lives of ordinary people have never been more significant. In recent times, the increased urgency to tackle climate change that has been accelerated by rapid industrialization and pollution requires STEM experts to develop novel solutions, and STEM-literate citizens to make informed decisions about public policies and to make changes in their personal lives. These grand challenges are also detailed in the 17 UN Sustainable Development Goals as a call to action for peace and prosperity for a common future (United Nations, 2015). Singapore, as an active global nation, needs to play its part in contributing to knowledge and solutions to the grand challenges identified.

The key skills growth areas for the continued development of Singapore's society and economy are those related to (1) the digital economy, (2) the green economy, and (3) the care economy (SkillsFuture Singapore, 2021). Of the top 20 job roles in the digital economy, 46% require technology application, data analytics, market research automation application, and consumer intelligence analysis. For the green economy sector, 25% of the job roles identified require skills for implementing and managing sustainable practices such as green process design and carbon footprint management. In the care economy sector that delves into technology enablement and community collaboration to build a more inclusive society, 28% of the job roles deal with conduct and ethics, stakeholder management, and inclusive practices (SkillsFuture Singapore, 2021). The skill sets for the various job roles identified for Singapore's future economy are STEM-related, and hence schools have to respond by ensuring that students are familiar with multi-disciplinary knowledge and skills to be fluent consumers and workers in the future.

Against this background of local economic needs and global demands for a sustainable future, Singapore's STEM education continues to flourish in K-12 schools. In Singapore, STEM education has varied interpretations ranging from mono-disciplinary learning of science and mathematics to integrated forms of problem-solving requiring knowledge and skills from different disciplines. Singapore students continue to excel on international comparative platforms such as the Trends in International Mathematics and Science Studies (TIMSS) and the Programme for International Student Assessment (PISA). In the 2019 TIMSS, Singapore students came top (Mullis et al., 2020) in the world. However, the data from the 2020 Census of the Singapore population suggest that among university students, the proportion of STEM graduates has decreased, and the business and administration course of study has overtaken engineering studies as the choice field of studies for males. Further, the percentage of graduates from engineering, information technology, and natural and mathematical sciences courses of study have all declined for both males (51.6% in 2010 and 44.5% in 2020) and females (25.1% in 2010 and 20.2% in 2020). Besides excellent showings in international comparative studies, perhaps more can be done to motivate students to go into STEM-related fields of study.

Structure of the Education System in Singapore

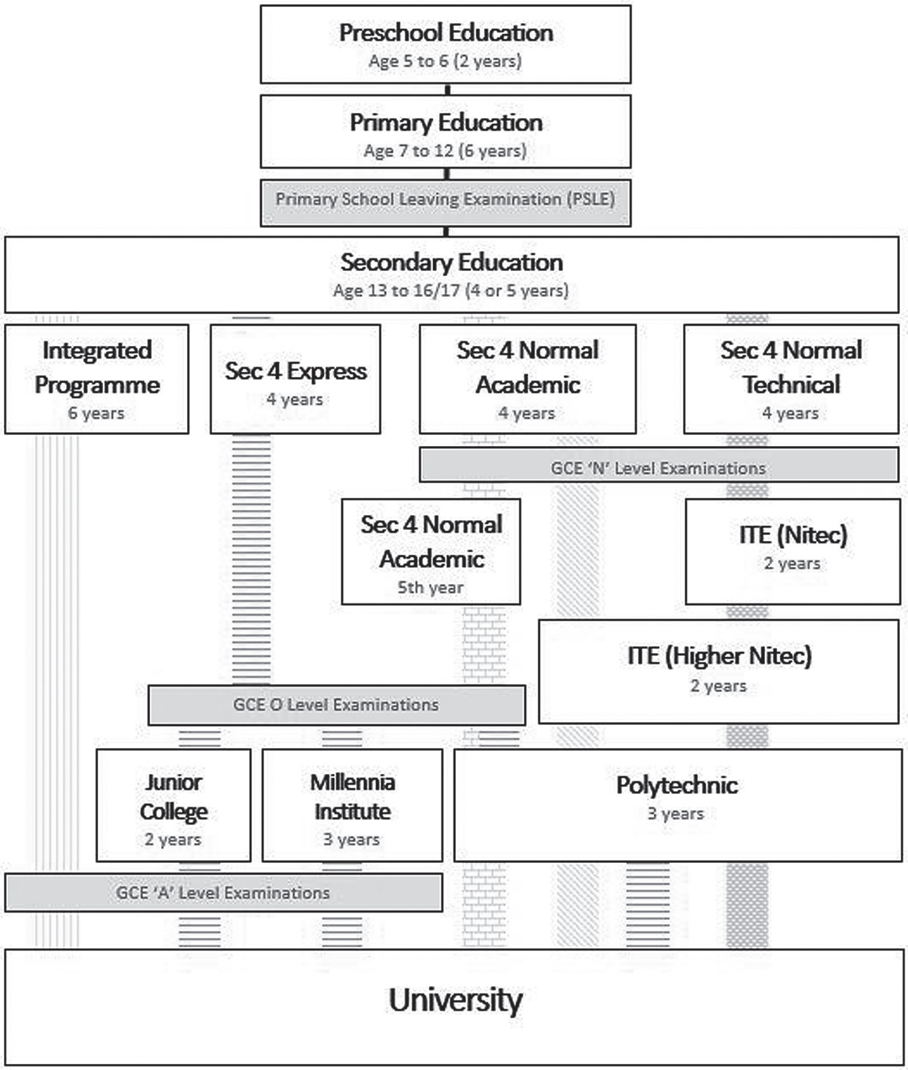
While preschool education is not compulsory, all Singapore citizens born after January 1, 1996 and living in Singapore must attend a national primary school unless they have been granted exemption. Education in Singapore is highly subsidized for Singapore citizens. The formal school experience for children in Singapore starts with a six-year primary school program which is usually followed by a four- or 5-year secondary school program. Generally, upon graduation from secondary school, most students either opt to attend a 2- or 3-year pre-university program or to be enrolled in a diploma program in one of Singapore's five polytechnics (see Figure 1 for more details of alternatives).

Singapore's education system considers the learning needs of different students, and provides multiple educational pathways for children to realize their education aspirations. As can be seen in Figure 1, after acquiring the fundamental literacy and numeracy skills in primary school, students will attend one of the four tracks in secondary school. Students who are eligible for the Integrated Programme (IP) can enroll in a 6-year program where they will take the General Certificate in Education Advanced Level (GCE 'A' level) examination or the International Baccalaureate (IB) at the end of 6 years to qualify for a place at a university.

The vast majority of students enroll in a 4-year Express course of study in a secondary school. These students will take the General Certificate in Education Ordinary Level (GCE 'O' level) examinations at the end of 4 years. With their 'O' level results, they can either apply for a 2-year course of study at a junior college for their GCE 'A' levels or a 3-year course at the Millenia Institute to complete their GCE 'A' levels to qualify for a place at a university.

Students can also be placed in a 5-year Normal course of study in a secondary school. This 5-year Normal course is sub-divided into Normal (Academic) and Normal (Technical) tracks. Students from the two Normal courses will take the General Certificate in Education Normal Level (GCE 'N' level) examinations after 4 years. The results of the 'N' level examinations determine if Normal (Academic) students will continue with the 5th year of study and take the GCE 'O' levels examinations or if they will proceed to take a 2-year course at the Institute of Technical Education. For students in the Normal (Technical) course of study, the 'N' level results will allow them to enroll in a course of study at the Institute of Technical Education. While the learning trajectory is different for different students, all the tracks present opportunities for students to pursue a university course of study. The opportunities to study mathematics and science are available at every grade level of study.

Figure 1 Main stages in the Singapore education system



Governmental Support of STEM Education

The academic syllabus in Singapore national schools is decided by the Ministry of Education (MOE). All national primary, secondary, and pre-university schools follow a common curriculum, which is kept current through curriculum review cycles that typically take place once every 6 years. During such a curriculum review cycle, curriculum developers from the MOE, heads of departments from schools, experts from institutes of higher learning (IHLs) and industries are invited to offer their expert feedback. New resources are developed and a trajectory for teacher professional development would also be initiated. There is a close tripartite relationship between the MOE, IHLs, and schools to ensure that the curriculum remains current and new ideas are meaningfully introduced (Chin & Poon, 2014). For instance, ideas related to the impact of climate change have been introduced to the A-level 8876 biology syllabus at the H1 level[1] from 2022. This inclusion takes into consideration the current global efforts to reduce damage to our environment (MOE, 2022b). While the national curriculum is centrally decided, the implementation of the curriculum is local. Schools and teachers are given the autonomy to plan lessons and activities based on the resources that they have to benefit their learners who could have differing learning needs and abilities.

For STEM education, a similar pattern of curriculum changes and planning is also observed. The government's support, mandate, and influence for STEM education takes the form of resource allocation, policy documents, as well as expertise availability.

1 A-level courses can be offered at three levels – H1, H2, and H3. These correspond to basic, normal, and advanced levels of conceptual learning.

The Status of STEM Education

There are multiple understandings and models of STEM education, from monodisciplinary to integrated STEM, or from interdisciplinary to transdisciplinary. In this chapter, we base our description of the status of STEM education in Singapore on both monodisciplinary learning of science, mathematics, and engineering (taught as design & technology in Singapore) and integrated STEM learning. This stance is taken since STEM education has traditionally been largely monodisciplinary and it is only in the last decade that integrated STEM learning has been making its way into schools.

Contexts of K-12 STEM Education

Currently in Singapore, K-12 STEM education is carried out in a monodisciplinary manner where science, mathematics, design and technology, and computing are taught as separate subjects, usually by different teachers. Monodisciplinary STEM learning has worked well for Singapore as evidenced by the high levels of scientific and mathematical proficiency among students (Mullis et al., 2020), and it is likely to continue as the *modus operandi* for science and mathematics education since school scheduling, teaching resources such as textbooks, and even teacher education and deployment are subject focused. Disciplinary STEM subjects are examinable and students' performance on examinations are used as the promotion criteria to higher levels of study. While disciplinary STEM learning has served Singapore well, there are ongoing efforts to explore possibilities of introducing STEM in an integrated manner to schools. The conversations among educators and policy makers on the role of integrated STEM education in the Singapore education landscape started somewhere in late 2019 and is still ongoing. Preliminary discussions point to using integrated STEM learning to help students make connections of disciplinary knowledge to solve problems. As such, there was an understanding that should integrated STEM be implemented systematically in schools, it should not be an examinable subject. At the point of writing this chapter, the policy papers regarding integrated STEM learning are still being discussed.

STEM Education System/Framework

Early years

In Singapore, children typically start attending pre-school at 5 years old, before they start formal primary school education at the age of 7. The pre-school curriculum varies across different schools, although there is the common goal of providing preschoolers with opportunities to learn social skills and also basic literacy and numeracy skills.

Primary school

Primary school education takes 6 years, from primary 1 to primary 6. The 6-year primary school program culminates in the Primary School Leaving Examination (PSLE) which is a national placement examination for secondary schools. As of 2020, there were 180 primary schools in Singapore catering to 232,650 students (MOE, 2021a). The goal of primary school education is to build in the children a strong foundation generally in literacy, numeracy, and problem-solving, while nurturing sound values and good habits. To this end, primary 1 and 2 students study English, Mother Tongue[2], Mathematics, Art, Character and Citizenship Education, Physical Education, and Social Studies. The strong literacy and numeracy skills lay the foundation for students to learn primary school science from primary 3 through a 4-year program that is divided into lower block (primary 3 and 4) and upper block (primary 5 and 6).

The goal of science education in *Singapore is Science for Life and Society*

2 Mother tongue languages include Chinese, Malay, Tamil, or Hindi depending on the student's ethnicity. If a student's race is Chinese, he/she will take Chinese language as the mother tongue. Similarly, if their ethnic group is Malay, they will take Malay language as their mother tongue class.

(MOE, 2021). *Science for Life and Society* is supported by three key ideas of literacy, namely personal/functional, civic/cultural, and professional/economic. To develop these three forms of literacy, students' learning is grounded in strong science fundamentals of scientific knowledge, practices, and values. To develop Singapore students' numeracy skills, mathematical problem-solving forms the core of the mathematics curriculum framework, which focusses on the five key areas of mathematics: (1) attitudes, (2) skills, (3) concepts, (4) processes, and (5) metacognition (MOE, 2021).

The primary science curriculum in Singapore is thematic in nature with topics in science organized around the themes of Systems, Interactions, Energy, Diversity, and Cycles. In planning science learning experiences, teachers are guided by the three key practices of ways of thinking and doing (WOTD), nature of science (NOS), and science, technology, society, and environment (STSE) (MOE, 2021). Science and mathematics are taught as separate subjects in Singapore primary schools.

Secondary school

As at 2020, there were 136 secondary schools in Singapore catering to 162,071 students from ages 13 to 16 or 17 years (MOE, 2021). It is mandatory for all secondary 1 and 2 students to take science and mathematics, which are taught as separate subjects. Science is taught as integrated science with the biology, chemistry, and physics topics organized around five themes (Scientific Endeavor, Models, Interactions, Systems, and Diversity). This thematic way of organizing science learning is similar to that in primary science.

At the upper secondary level (secondary 3 and 4), students can choose which science subjects they want to study, as biology, chemistry, and physics are offered as different subjects. For mathematics, all students must take elementary mathematics, and students with an aptitude for mathematics can opt to take a second mathematics subject called additional mathematics. Each subject is taught by a different teacher. The curricular syllabus of mathematics, biology, chemistry, and physics is jointly designed by the Singapore-Cambridge General Certificate of Education Ordinary Level (GCE 'O' Level) team.

There are two specialized mathematics and science secondary schools in Singapore. In 2005, the NUS High School of Mathematics and Science (NUS High School) welcomed its first batch of students. NUS High School was set up to nurture the top mathematics and science students in Singapore. NUS High School has an enrolment of about 1,300 students (NUS High, 2022). NUS High School is affiliated to the National University of Singapore (NUS) and offers a 6-year integrated program. Students graduate from NUS High School with the NUS High School Diploma that is recognized by renowned universities both locally and internationally. In 2010, Singapore's second specialized STEM school, the School of Science and Technology (SST) was set up. With an enrolment of about 800, SST offers a 4-year program with students taking the GCE 'O' level examination at the end of the course. These two specialized STEM schools serve to augment the Singapore STEM education landscape by offering a different pathway for students who would like to start their pursuit of science and mathematics early.

Applied learning programs in schools

The Applied Learning Programme (ALP) is an initiative by the MOE and is intended to help students make meaningful connections between what they learn in school and the real world. It emphasizes the application of knowledge and skills learnt in schools to problems that may arise in industries and society. It is a non-examinable subject. ALP is available in all secondary schools and will be expanded to all primary schools by 2023.

Schools can offer ALP in one of six areas: (1) STEM, (2) languages, (3) humanities, (4) business and entrepreneurship, (5) aesthetics, and (6) interdisciplinary (MOE, 2022a). There are five key areas under the STEM ALP program ─ (1) cities and urban technology, (2) emerging technologies, (3) future of transportation, (4) health and food science, and (5) sustainability. Of all the 288 schools that offer ALP in 2022, 119 schools (or 41%) have STEM-related ALP, 53 schools (or 19%) specialize in languages, 22 schools (or 8%) offer humanities, 11 schools (or 4%) offer business and entrepreneurship, seven schools (or 3%) offer aesthetics, and 40 schools (or 14%) offer interdisciplinary projects. Based on our survey of the schools' websites, 11% of the schools did not indicate their specific ALP specialization (MOE, 2022a). The higher percentage of schools choosing STEM-related ALP for their students suggests both interest in STEM as well as a recognition of the importance of knowledge in this area for society in the future.

The emphasis of STEM ALP in schools varies. For instance, in Bartley Secondary School, secondary 1 students acquire basic knowledge of fragrances, learn about separation techniques to extract essential oils, learn how to use software such as CAD to design for 3D printing, and use micro:bit coding in their projects. These acquired knowledge and skills are further refined as the students move to secondary 2 where they apply them to create prototypes. In secondary 3 and 4, the school collaborates with a local polytechnic to offer an advanced elective program on Perfumery and Cosmetic Science for interested students. In another school, Boon Lay Secondary School, the students engage with the idea of sustainability, learn how to code, and also build solar cars in secondary 1. When students progress to secondary 2, they learn CAD and app development, which they apply to sustainability projects. In secondary 3 and 4, interested students take up elective modules related to different STEM issues. Yet other schools provide exposure to other areas such as clean energy, aerospace and aviation, aeronautics, health sciences, forensic science, food sciences, drones and robotics, transportation, and game design.

The ALP model adopted by schools for students in the lower grades is characterized by broad-based technology and design skills building programs.

This exposure allows students to develop basic competencies in STEM and to discover their related strengths and interests. Those who have a passion for STEM can proceed to pursue STEM elective courses at higher grade levels. The general-specific model for ALP implementation maximizes the use of available resources while making STEM accessible to all students, and offers avenues for specialization.

Special education schools

There are 22 special education schools in Singapore. These schools cater to students with different learning needs. Students with autism spectrum disorder, intellectual disability, multiple disabilities, and sensory impairment can enroll in one of the special education schools where they receive expert support to facilitate their learning (MOE, 2021). Of these 22 schools, 10 offer STEM programs including understanding ICT and assistive technologies, robotics and Autodesk 3D design, and digital illustration.

Post-secondary school

There are various post-secondary school pathways for students. Students who wish to pursue the GCE 'A' level certificate can enroll in one of the 11 junior colleges or centralized institutes. In 2020, there were 26,005 students studying in junior colleges or centralized institutes (MOE, 2021a). The GCE 'A' level course offers a range of STEM-related subjects such as biology, chemistry, physics, computing, mathematics, and further mathematics. The syllabus content of these subjects at the post-secondary level is more complex compared to secondary school. Students can take a maximum of four subjects for the 'A' levels.

One other post-secondary school possibility for students is a 3-year polytechnic course in one of the five polytechnics. In 2020, there was a total enrolment of 66,933 students in the polytechnics. The STEM- related courses offered include engineering sciences, health sciences, information technology, and natural & mathematical sciences. These courses were taken by 38,484 students, or 57.5% (MOE, 2021a) of the total polytechnic enrolment.

Another post-secondary school possibility for students is to enroll in a work skills-based course of study at the Institute of Technical Education (ITE). On average, ITE has 28,000 full-time students in three campuses across the country. The ITE certification includes the National ITE Certification (NITEC) or higher NITEC and technical diplomas. The STEM-related courses offered include chemical technology, civil & structural design, electrical engineering, cyber & network security, IT systems & networks, and business information systems (ITE, 2022). The number of students enrolled in STEM-related courses (applied & health sciences, electronics & infocomm technology, and engineering) totaled 17,245 or 61.5% (MOE, 2021a) of the student enrollment.

The university is typically the goal of many as the final stop for their formal education in Singapore. There are six public universities in Singapore with a total enrolment of 76,082. Of the total number of university undergraduates, 36,005 or 47.3% are enrolled in a STEM-related course (dentistry, engineering sciences, health sciences, information technology, medicine, or natural & mathematical sciences) (MOE, 2021a).

Table 1 Education institutes with STEM programs

Category	Description	Number
Comprehensive schools (Primary)	Provide fundamental learning of mathematics from grades 1 to 6 and learning of science from grades 3 to 6. The learning of conceptual knowledge, skills, and dispositions in science and mathematics lay the foundation for and prepare students to learn mathematics and science at higher grade levels.	180

Table 1 (continued)

Category	Description	Number
Comprehensive schools (Secondary)	Build on the foundational knowledge and skills of mathematics and science learning from primary schools. From integrated science in secondary 1 and 2, specialization in biology, chemistry, and physics occurs at secondary 3, 4, and 5. Some schools have special STEM programs to develop students who are interested and more talented in STEM learning.	136
Comprehensive schools (Junior College or centralized institute)	Advanced learning of mathematics and science for students who are interested in pursuing the study of mathematics and science at tertiary level. Science subjects offered at junior colleges and centralized institutes include biology, chemistry, physics, and computer science. Mathematics can be studied at the basic level of mathematics C or at a deeper level of further mathematics.	11
Specialized STEM schools	Targeted for students from 13- to 16 years-old who are talented and interested in mathematics and science. The students are actively exposed to science mentorship programs and work on different science and mathematics related projects.	2
Institute of Technical Education	Specialized institute focusing on job skills ranging from electronic engineering to civil and structural engineering design. The curriculum is geared toward acquisition of practical STEM-related skills for a wide range of industries.	3
Polytechnics	The mission of polytechnics is to train professionals to support the technological and economic development of Singapore. Graduates from the polytechnics have strong practice-based skills that are much sought after by industries.	5
Universities	Of the six universities, three (National University of Singapore, Nanyang Technological University, and Singapore University of Technology and Design) have programs to develop top talents in mathematics, science, engineering, and technology.	6

STEM-related Activities in Non-formal Education

Beyond the formal school curriculum, students in Singapore all participate in co-curricular activities (CCA) that typically occur after class time. Students are given the autonomy to choose a CCA that interests them. Examples of CCAs include scouts, girl guides, netball, volleyball, tennis, drama, band, and choir. The intention of CCAs is to develop students more holistically beyond academics. Some schools offer CCAs such as robotics, science club, environment club, and computer club, and these CCAs are gaining in popularity in schools. To ensure that the learning experience during these CCAs is meaningful and current, schools often invite experts or hire coaches to mentor students in expertise areas. Students with keen interest in STEM learning can extend their involvement with STEM through involvement in these CCAs.

Besides formal STEM learning in schools and specialized programs such as STEM ALP, there are also organizations and industries that support informal STEM learning. Three examples of such government affiliated organizations are the Science Centre Singapore, A*STAR, and the Infocomm Media Development Authority (IMDA). Science Centre Singapore has a dedicated unit established in 2014, STEM Inc., which specializes in STEM education and outreach. Besides offering expert advice to schools for their STEM ALP programs, STEM Inc. also organizes workshops for students and teachers, and helps connect schools to the industries. Schools can sign up for teacher training workshops such as basic electronics, mBot, micro:bit, Arduino, Internet of Things, laser cutting and engraving, 3D computer aided design, 3D printing and scanning, and PCB design and fabrication. Some of these programs are made more authentic through industry partnerships to enable students to job-shadow engineers and scientists (Science Centre Singapore, 2022). To encourage students to participate in science and engineering programs and to spot talents in these fields, Science Centre Singapore also runs various award programs such as the Young Engineer Award (YEA). The entire suite of programs and awards offered by Science Centre Singapore makes STEM ideas and knowledge accessible to the masses and as such, Science Centre Singapore is a crucial partner in the Singapore STEM education ecosystem.

Another organization that supports informal STEM learning is the Agency for Science, Technology and Research in Singapore (A*STAR). A*STAR plays a key role in nurturing and developing talent and leaders for Singapore research institutes and industries. As part of its continuous efforts to nurture young scientific talents for Singapore, A*STAR offers attachment programs to interested secondary school and junior college students. These students are attached to selected researchers to carry out investigative study in science or engineering. A*STAR also offers a scholarship program to attract the most brilliant and passionate science and engineering talents to pursue careers in research (A*STAR, 2022).

The IMDA in Singapore develops and regulates the infocomm and media sectors in a comprehensive and holistic manner so as to create opportunities for growth in talent, research, innovation, and enterprise. One of its efforts includes a Lab on Wheels program that aims to bring new and emerging technologies to schools and the community. Through different themed buses, the Lab on Wheels brings STEM learning experiences all over the island. Cyber security, artificial intelligence, and immersive media are examples of the different themes that have been featured (IMDA, 2019).

Private companies, industries, and non-government organizations in Singapore also offer STEM-related programs. For instance, in 2018, technology giant IBM launched the Pathways in Technology Early College High-Schools (P-TECH) School Model in partnership with ITE and Singapore's five polytechnics (Toh, 2018). Community groups such as Discovering without Borders work with underprivileged children to bring STEM concepts, skills, and experiences to them. There are also numerous private enrichment centers that run STEM holiday camps, enrichment classes, and attachments for students of different grade levels. The diversity and popularity of informal STEM learning opportunities suggest that the STEM learning ecosystem is flourishing and is popular with parents and students alike.

STEM Learning Assessment and Career Development

As STEM learning in Singapore remains largely mono-disciplinary, assessment of STEM learning is through students' results from school-based tests, examinations, as well as national standardized tests such as the PSLE, GCE 'O' level, GCE 'A' level examinations or the international baccalaureate. The assessment results at each grade level determine students' emplacement at the higher level of study. Consequently, examinations are considered by many in Singapore as high stakes.

Internationally, for PISA 2018, 93% of students in Singapore attained a level 2 or higher for mathematics. This is higher than the OECD average of 76%, although it is lower than the 98% in Beijing, Shanghai, Jiangsu, and Zhejiang (China). Students who attained a level 2 for mathematics demonstrate that they are able to interpret and recognize, without direct instructions, how a situation can be represented mathematically. Further, 37% of Singapore students scored a level 5 or higher in mathematics. The OECD average is 11%. Students who attained Level 5 have demonstrated the ability to model complex situations mathematically, and to select, compare, and evaluate problem-solving strategies.

For science for PISA 2018, 91% of students in Singapore attained a level 2 or higher. This percentage is higher than most OECD countries as the OECD average is 78%. At level 2, students know the correct explanation for familiar scientific phenomena and are able to identify if a conclusion is valid based on the data provided. Further, 21% of Singapore students were top performers in science with a science proficiency at level 5 or 6. The OECD has an average of 7% of students attaining these two levels. Students who attain level 5 or 6 proficiency demonstrate that they can creatively apply their knowledge of and about science to a wide variety of situations, including novel situations (OECD, 2018).

Doing well in STEM subjects in schools is beneficial for students who want to pursue STEM-related courses of study at tertiary level. For instance, several engineering courses at NUS and Nanyang Technological University (NTU) in Singapore have as pre-requisites a good grade in mathematics and at least a pass in GCE ‘O’ level physics. For medical school, the admission criteria require students to have studied chemistry and either biology or physics as the other STEM subject at GCE ‘A’ level. As such, to pursue a STEM course of study at tertiary level, students must have studied and met minimum grade requirements at the secondary school and junior college levels.

STEM Teacher Qualifications, Pre-service Training, and In-service Professional Development

To ensure a high quality of mathematics and science education in Singapore, teacher quality is fundamental. Teachers in national schools under the MOE must have obtained their teaching certification from the National Institute of Education (NIE), Singapore. The NIE is the sole teacher education institution in the country and offers a wide range of courses leading to qualifications such as Bachelor of Science (Education), Post-Graduate Diploma in Education (PGDE), Master of Education (Science), PhD and EdD. In 2020, the intake for NIE was 530 students, 71% of whom were female (Data.gov, 2022). The Bachelor of Science (Education) program is a 4-year program where students learn STEM subject matter. They also take pedagogy-related courses from the 2nd to 4th years. During the program, students have opportunities to intern in schools to learn how mathematics and science are taught. They have a 5-week teaching assistantship in year 2, a 5-week practicum in year 3, and a final 10-week practicum in year 4. To ensure the development of a robust and in-depth understanding of scientific and mathematics concepts, pre-service teachers enrolled in the BSc (Ed) program have to complete a final-year research project where they work with practicing scientists or mathematicians on a research project for 6 months. This provides the pre-service teachers with authentic experiences of science and mathematics as practiced in the real-world (Tan et al., 2021).

Students enrolled in the 16-month PGDE (Secondary) program typically already have a degree in a STEM field from a recognized university. Students enrolled in the PGDE (Primary) program might not have a degree in a STEM field, although most would have a first degree. STEM teachers enrolled in the PGDE program would take pedagogy-related courses and also need to fulfil two further requirements – a 4-week internship and a 10-week practicum. For primary schools, teachers are generalists and are trained to teach English, mathematics, and science. During preservice teacher education, all primary school teachers take courses on pedagogies in mathematics and sciences. These courses introduce ideas such as the nature of science and mathematics, assessment principles, and strategies for planning meaningful learning. Secondary school teachers are specialists, with each teacher specializing in two teaching subjects. Typically, for STEM teachers, their specialization could be mathematics and physics, mathematics and chemistry, biology and chemistry, physics and chemistry, or physics and biology. There are currently no preservice teacher courses that focus specifically on integrated STEM learning.

In 2021, there were 32,152 teachers in Singapore of whom 23,004 (or 71.5%) were female. This proportion corresponds with preservice teacher recruitment. The median for the years of service for both male and female teachers is 5 to 9 years (22.6%) and the median for the age of both male and female teachers is 30-34 (19.6%). There is however no data available specifically for STEM teachers (MOE, 2021a), but we expect it to correspond to the trend of teachers service-wide. As the current school curriculum is organized around individual STEM subjects, there are ongoing efforts to raise the awareness of integrated STEM learning among STEM teachers, particularly among science teachers.

In summary, the formal education system in Singapore builds up STEM competencies from primary schools to post-secondary education in the areas of knowledge, skills, and attitudes. This sustained exposure to STEM-related ideas serves two purposes – (1) to ensure the development of personal and functional scientific and mathematical literacy among students in Singapore, and (2) to establish the pipeline for a STEM-competent workforce for Singapore. Collectively, in 2020, the ITE, polytechnics, and universities offered STEM-related knowledge and skills through formal education to 91,734 students. In 2021, the government expenditure on education was approximately SGD 13.62 billion, which is 7.8% higher than the revised expenditure compared with 2020 (Ministry of Finance, 2021). This generous budget allocated for education, ensuring that top talents are recruited to support education in Singapore, is evidence of the strong support rendered by the government for education (which includes STEM education).

Current STEM Education Reforms and Policy Discussions

In November 2019, Singapore revealed the revised science curriculum framework that has Science for Life and Society as the goal for science education in Singapore (CPDD, 2019). Three fundamental domains of conceptual knowledge, practices of science, and attitude, values, and ethics were identified as key considerations in planning and evaluating meaningful science learning experiences. There is ongoing professional development discussing how aspects such as Science-Technology-Society-Environment can be incorporated into students' science learning experiences to make science learning more meaningful and authentic.

There are currently interest and discussions around how integrated STEM education can be introduced into schools to augment science and mathematics teaching. Ideas being explored include viewing integrated STEM learning as another teaching strategy, and using integrated STEM as projects that students can work on after school. These discussions were still ongoing at the time of writing this chapter and, hence, changes to STEM education policies are expected.

Trends and Issues in STEM Education

In this section, we examine the trends and issues in STEM education in Singapore based on current observations and the predicted needs of the country. Based on the findings from SkillsFuture Singapore (2021) on the skills needed for the three key growth areas (digital economy, green economy, and care economy) for Singapore, we will discuss the trends and issues related to (1) the reported number of STEM-related jobs, and (2) encouraging greater female representation in STEM-related positions and jobs.

Major Trends in STEM Education

1. Reforming STEM through STEM education review

Following the recommendations of the STEM Education Review Taskforce set up by the MOE, there have been concerted efforts to address students' declining interest in STEM courses and careers. The recommended efforts are focused on improving STEM teaching and learning and encouraging stronger interest in STEM careers. To this end, greater synergies in the Singapore STEM ecosystem need to be established in order to develop a passionate and skilled STEM teaching fraternity who will lead and inspire students to be interested in STEM learning and careers. The key stakeholders in the STEM ecosystem comprise the MOE (specifically, MOE Sciences Branch, Academy of Singapore Teachers, and Science Centre Singapore) and the NIE. They are tasked to strengthen teachers' beliefs and readiness to deliver STEM education by offering a range of pre- to in-service teacher education opportunities in formal and informal education settings. It is noteworthy that each stakeholder approaches

STEM teacher education differently to cater to teachers' varying readiness and students' different needs. This also explains why the STEM curriculum is framed as a spectrum of approaches and learning experiences comprising varying degrees of integration, learning foci (concept or skill development to experiential learning), nature of tasks (routine to non-routine), and problem-solving approaches (solution to problem-centric).

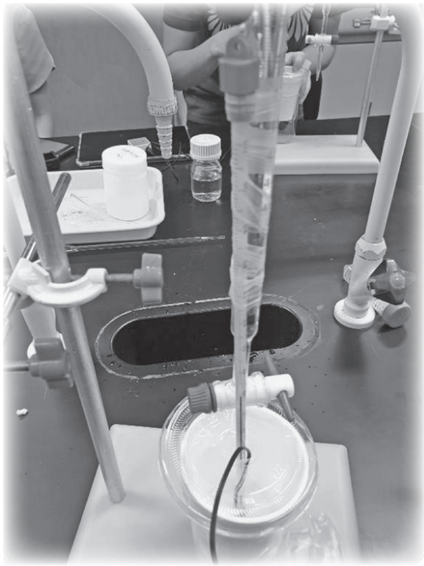
2. Increasing the momentum for STEM education professional development

With greater awareness of the benefits and need to introduce ideas of integrated STEM problem-solving in teaching and learning, teacher professional development is required. The four key stakeholders of STEM education in Singapore (namely, MOE Sciences Branch, Academy of Singapore Teachers and Science Centre Singapore, and the NIE) provide support for teachers in the areas of STEM capacity-building to enact STEM lessons by conducting courses that deepen teachers' disciplinary knowledge and practices (DKP) to do vertical integration within each discipline and to broaden teachers' DKP to do cross-cutting integration of more than one discipline. Teaching and learning materials that afford STEM learning experiences are currently being developed by the MOE curriculum officers, and are being trialed in schools to gather feedback for improvements. These materials will become resources for STEM teachers' adoption or adaptation in the formal or after-school curriculum. All-year-round STEM activities take the form of STEM or STEAM festivals, competitions, and seminars. Workshops, and so on, are run by the Science Centre Singapore, for schools to engage teachers, students, and the general public.

Given the expansiveness of STEM activities in Singapore, we will focus on the work of the NIE in STEM education as the programs cut across pre- to in-service teacher education levels and prepare them to teach in formal and informal settings. In particular, we will highlight the two areas of work in STEM teacher preparation.

As mentioned in section 2.5, NIE runs the PGDE and BSC(Ed) program for teachers teaching STEM subjects including science, mathematics, computing, and design and technology. There are some efforts within the program to expose undergraduates and preservice teachers to STEM education by anchoring the STEM lessons in a subject and infusing other disciplines into those lessons. There are also lessons that discuss vertical integration within a subject. For instance, in one course in the PGDE (Chemistry) program, preservice teachers were introduced to an IoT-enabled device, PocketLab, and were tasked to carry out an experiment to determine the enthalpy change of neutralization of a strong base and a strong acid. Using the temperature sensor connected to the PocketLab and a clinical glass thermometer, the preservice teachers determined the temperature change recorded on the device and apparatus, compared the values to the theoretical value, and concluded the accuracy of the apparatus. However, in the process of setting up the experiment (see Figure 2) for data collection, they had to deliberate on the set-up to collect the best temperature change, manipulate the data, analyze the data using Excel and regression analysis, and perform calculations. These activities were anchored within chemistry, but they also brought in mathematics and technology. They also integrated more than one chemistry topic – acids and bases, and thermochemistry. In NIE, there are two undergraduate elective courses that the university students can take. One of the courses focuses on gender issues in STEM and the other on the integration of STEM. These courses provide undergraduates with exposure to STEM education discourse from a social science and education perspective.

Figure 2 Titration setup with temperature probe connected to an IoT device and clinical thermometer to infuse technology into a chemistry-focused lesson integrating the topic on volumetric analysis of a strong acid and a strong base and thermochemistry



In April 2023, NIE will launch a Certificate in STEM Curriculum Development for Singapore in-service teachers. This program augments existing disciplinary professional development programs in biology, chemistry, and physics to introduce ideas that are more specific to the integration of STEM disciplinary content and practices. It will do so by bringing in topics in emerging technologies related to sustainability and digital literacies. For example, teachers will learn about the 3D printing of the human body to create integrated STEM lessons incorporating STEM concepts and practices. They will learn about the applications of STEM content knowledge in creating solutions for specific users. In addition to learning the new content, they will also engage in pedagogical discussions about how to enact the lessons meaningfully in the classroom to facilitate students' development of 21st century competencies including problem-posing, problem-scoping, solution-refining, design, and prototyping.

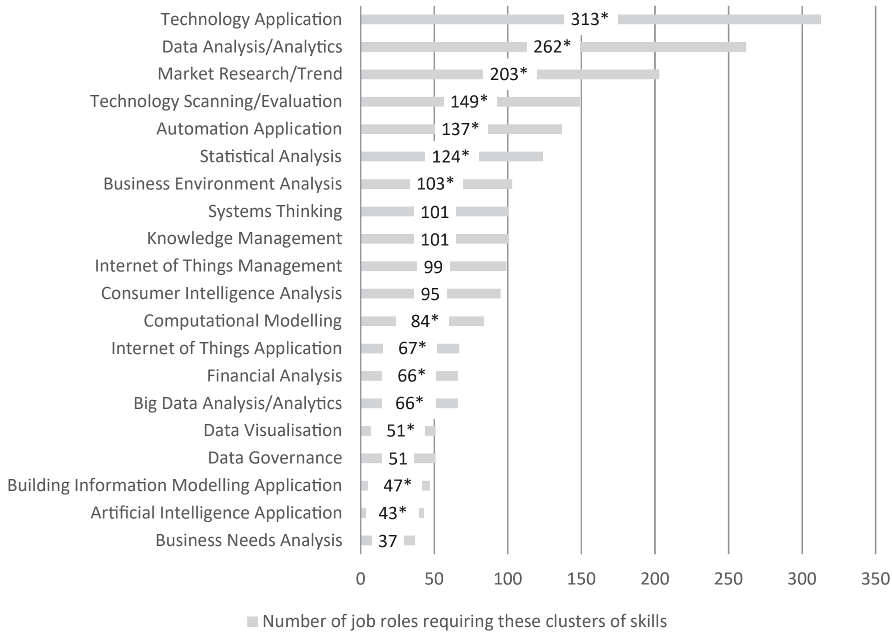
Teachers may design lessons that foreground a complex, persistent, and extended problem for students to solve. They may also present students with an existing solution and get them to improve on it. They can also have students brainstorm and identify a group of people who may benefit from the solutions of 3D printing and create something useful for them, hence imbuing social empathy. During the lessons, the teachers will hear from STEM experts, meet them for dialogue, and visit a STEM workplace. They will have more authentic and current experiences of the work that STEM professionals do and be able to inspire their students with anecdotal accounts of what they had experienced. In addition to this structured certification program, NIE also already offers more than 10 stand-alone STEM professional development courses for teachers. At the graduate level, there are two Master's level courses in STEM education that are concurrently offered as in-service courses. Hence, there is a range of opportunities for in-service teachers to learn about integrated STEM at the macro (histories and policy), meso (classroom), and micro (strategies and tools) levels.

Besides formal programs, there are events organized to engage interested teachers in STEM-related activities to hone their skills in planning integrated STEM lessons. For instance, at NIE, all science and mathematics pre-service teachers have to participate in an annual STEM hackathon to enable them to experience STEM problem-solving. Through such involvement, pre-service teachers have lived experiences of hackathons and would be in a better position to organize such events when they are in schools. In-service teachers can participate in the annual Empowering STEM Education Professionals program organized by meriSTEM@NIE. In this program, teachers form themselves into interdisciplinary teams and plan integrated STEM lessons with complex, persistent, and extended problems at the core (Tan et al., 2019). This event offers teachers a platform to present and share their integrated STEM lesson ideas with other teachers to build their confidence and ability to engage with STEM problem-solving.

3. Meeting the increasing demand for STEM-related jobs

In the digital sector, Singapore needs 2,500 to 3,500 workers annually to fill technology jobs just in the financial sector alone, and the IMDA reported that there were about 19,000 technology-related jobs in Singapore in 2020 that were still not filled, as the graduates in infocomm from the polytechnics and universities were not taking up the jobs (Lim, 2021). The increasing importance of technology and digital skills in Singapore suggests that schools need to enhance efforts to introduce and motivate students to learn skills for the digital economy. As reflected in Figure 3, there are 2,199 job roles that require digital skills for the future economy of Singapore. Among the cluster of 20 digital skills identified, 14 are directly related to STEM: (1) technology application (technology-related), (2) data analysis or analytics (mathematics-related), (3) market research or trend analysis(mathematics-related), (4) technology scanning and evaluation (technology-related), (5) automation application (technology-related) , (6) statistical analysis (mathematics-related), (7) business environment analysis (mathematics-related), (8) computational modelling (technology-related), (9) internet of things application (technology-related), (10) financial analysis (mathematics-related), (11) big data analysis and analytics (mathematics- and technology-related), (12) data visualization (mathematics- and technology-related), (13) building information modelling application (technology-related), and (14) artificial intelligence application (technology-related) (SkillsFuture, 2021). The dominant knowledge and skills required for digital technology are mathematics- and technology-related. Teachers and curriculum developers can refer to the specific types of knowledge and skills required for each job role to plan mathematics or technology curricular programs to enhance students' real-world relevant learning experiences.

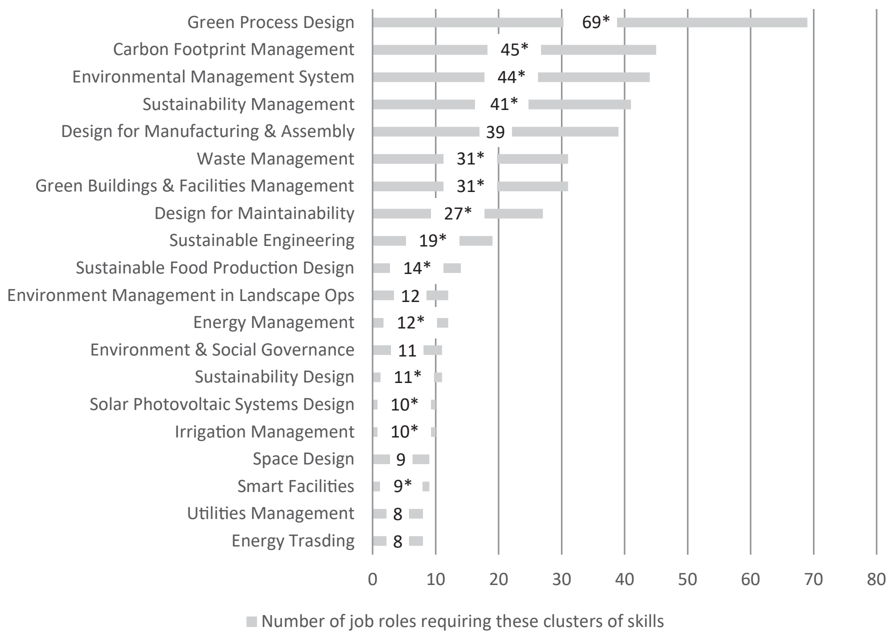
Figure 3 Job roles related to the digital economy



Note: *indicates STEM-related roles.
Source: SkillsFuture, 2021.

Besides the need for STEM-related skills and knowledge for the digital economy, STEM-related skills are also in demand in the green economy. As reflected in Figure 4, in 2021 alone there were 429 job roles that required skills related to the green economy. There are 20 skills listed in this cluster and 14 are directly related to STEM: (1) green process design (science- and engineering-related), (2) carbon footprint management (science-related), (3) environmental management systems (science-related), (4) sustainability management (science-related), (5) waste management (science- and engineering-related), (6) green building & facilities management (engineering-related), (7) design for maintainability (engineering-related), (8) sustainable engineering (engineering-related), (9) sustainable food product design (science-related), (10) energy management (science-related), (11) sustainability design (engineering-related), (12) solar photovoltaic system design (science- and engineering-related), (13) irrigation management (science- and engineering-related), and (14) SMART facilities. Compared to the digital technology cluster, the knowledge and skills for the green economy are generally science- and engineering-related.

Figure 4 Job roles related to the green economy



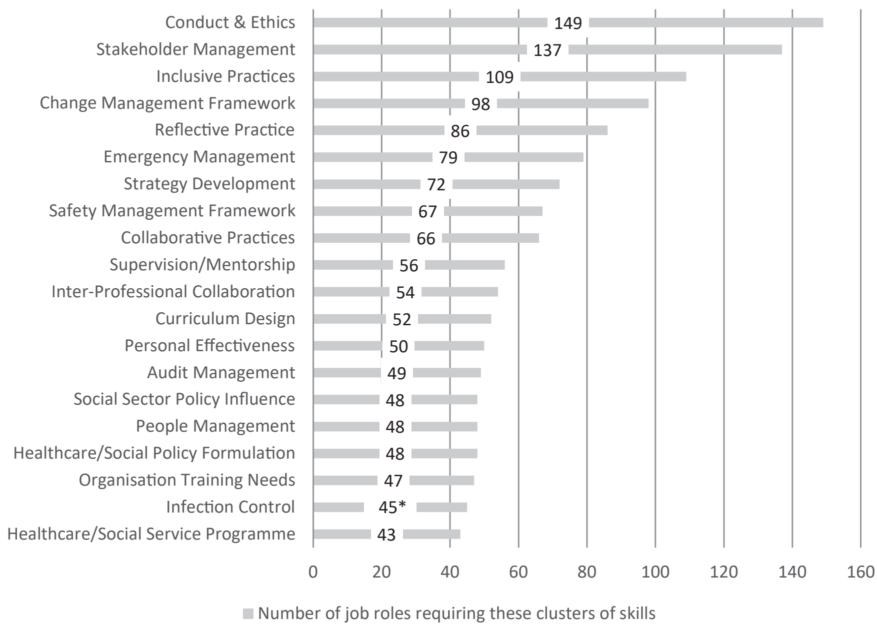
Note: *indicates STEM-related roles.

Source: SkillsFuture, 2021.

For the care economy, there were 1,402 job roles as of 2021 that require the 20 skill sets described in Figure 5, of which only one is directly related to STEM. The skill set for Infection control requires one to have strong science and mathematics skills.

Of the three emerging areas required to grow and sustain the economy, 29 of the 60 skill sets are STEM-related. This trend suggests a need to continue with our efforts to grow STEM education in schools so that more students are better equipped with the necessary knowledge and skills to support the Singapore economy and society. This is especially important since there were 29,130 job vacancies in Singapore as of September 2021 (Ministry of Manpower, 2021) and of these, 6,080 require specialized STEM-related knowledge and skills. Enhancing efforts to improve STEM education will also help to reduce the reliance on foreign skilled talent.

Figure 5 Job roles related to the care economy



Note: * indicates STEM-related roles.

Source: SkillsFuture, 2021.

4. Creating a culture to support lifelong learning and a versatile workforce

The SkillsFuture manifesto in Singapore aimed to and is in the process of re-defining learning and education. Starting in January 2016, every Singaporean aged 25 and above received S$500 of opening SkillsFuture credits to enroll in courses to learn and upgrade their skills. There have been two periodic top ups of S$500 each for every Singaporean since 2016. These SkillsFuture credits do not have an expiry date and hence Singaporeans can utilize them at their convenience. This national lifelong learning initiative is to ensure that the competencies of the Singapore workforce remain versatile and robust. An examination of SkillsFuture courses offered by tertiary institutions include STEM-related courses such as data science, SMART manufacturing, and 3D printing. The knowledge base of these rapidly evolving STEM disciplines requires continuous updates and upgrades of knowledge. As such, beyond school, the workforce needs to learn constantly to stay connected to the changes in the STEM landscape. It is certain that this trend of lifelong learning in STEM skills and knowledge will continue so that the workforce remains nimble to face changes.

The notion of lifelong learning also relates to daily living. With the rapid penetration rate of technological and scientific artefacts in our lives, Singapore society needs to increase its STEM literacy. For instance, during the pandemic, there was pervasive use of technology to enable contact tracing. Mobile apps became an essential tool for people and governments to contact trace. It was observed that courses related to the use of mobile technology were conducted during this period to ensure that older adults acquired the knowledge and skills to use their mobile devices so that they could go about their daily lives uninhibited. The use of video conferencing technology such as Zoom became ubiquitous to allow for people to connect with one another while physically separated. The older population should also be included in this change in the way we live. As such, moving forward, lifelong learning related to the use of new technologies will become increasingly important as Singapore moves towards being more inclusive.

5. Accelerating efforts to increase the number of women in STEM

Internationally, there has been attention paid to attracting more females to participate in STEM-related activities and to pursue careers in STEM (see Sakar et al., 2014; Williams et al., 2017). Reasons cited for the lower number of females in STEM-related careers include stereotyping girls' interests and abilities in STEM and a lack of genuine opportunities for girls to engage with STEM internships (Hobbs et al., 2017). Our Singapore leaders have also underscored the need for more women in STEM fields (see e.g., Ng, 2021). There are efforts from the ground to advocate participation of more women in STEM. For instance, questions have been raised in Parliament (MOE, 2020) on the measures to build students' interest in the growth areas of STEM and plans to encourage more females to pursue STEM-related courses of study, to embark on STEM-related careers, and to increase female representation in leadership roles in STEM. Currently, four in 10 students enrolled in STEM courses in the universities, polytechnics, and ITE are females. In the labor force, one third of residents employed in STEM in Singapore in 2020 were female (Ministry of Manpower, 2020). To increase female engagement in STEM careers, a S$250,000 bursary was set up in 2021 in the East Coast district in Singapore to support female students studying in STEM-related courses. This is expected to financially benefit at least 100 students annually (Yong, 2021). There are also several scholarships specifically targeted at females to pursue STEM courses of study at higher levels. For instance, the Singapore University of Technology and Design (SUTD) has a scholarship that is open to female Singapore citizens to pursue an undergraduate course of study in STEM. This Singtel-SUTD Women in Tech Scholarship is support by SingTel (one of Asia's leading communications technology groups). SUTD also has a parallel scholarship for female international students choosing to enroll in a STEM undergraduate course of study in SUTD. This scholarship is sponsored by the

Kewalran Chanrai Group (SUTD, 2022).

Additionally, efforts from non-government organizations such as United Women Singapore have started work towards narrowing the gender gap in STEM career opportunities through programs such as Girl2Pioneers that serve to encourage and engage girls from 10-16 years old to take up the study of STEM subjects in higher education and later, careers in STEM. The program, started in 2014, aims to reach 4,500 girls each year (UWS, 2022) and to date, more than 26,000 girls have participated.

The generous support from the community for more females to participate in STEM activities is an encouraging emerging trend. With the greater general push for STEM education by the MOE and a greater awareness of STEM knowledge and skills for the future economy, it is likely that more private enterprises and community groups will step up to offer support and programs geared towards supporting more females in STEM education.

6. Increasing research on STEM education

As a society that prides itself on being scientifically and technologically advanced, research on different aspects of STEM education is highly valued in Singapore. To better understand the impact of STEM education on students' development and on society as a whole, an integrated STEM education research center, meriSTEM@NIE, was set up in November 2018 by several NIE faculty members. meriSTEM@NIE carries out research on integrated STEM curriculum development, evaluation of integrated STEM learning, and development of STEM identities. Since its inception, meriSTEM@NIE has been successful in winning research grants and donations of more than S$2 million from private organizations and ministries. These generous grants and donations are indicative of the interest that the private organizations and ministries have in STEM education. In the last fouryears, meriSTEM@NIE has published more than 10 papers related to integrated STEM teaching, learning, and curriculum design. Based on the current trajectory of grants and publications, it is expected that the interest in STEM education research will increase in the near future.

Major Issues in STEM Education

This section discusses several issues related to STEM education in Singapore. We highlight the five most pertinent challenges to more pervasive adoption of STEM or integrated STEM education. While these issues are not new and are raised in the face of any educational change around the world, the severity of these issues is compounded when more than one discipline is brought together. We will also offer some insights into what has been done or can be done to address these issues.

1. Lack of a clear understanding of STEM

The STEM education academic and policy making communities do not have a clear definition of STEM. Oftentimes, STEM as a term encompasses both the singular and integrated disciplines, and the distinction is not clear. STEM has been used to refer to the mono-disciplines and integrated disciplines interchangeably, creating confusion for teachers who oftentimes question how STEM is different from how they are currently teaching STEM subjects in schools, and whether they are teaching STEM as espoused by the MOE. In 2021, the MOE provided greater clarity by showing that the STEM curriculum may not be one kind of learning experience; rather teachers may think of the STEM curriculum as varying in levels of integration (monodisciplinary to integrated) and in applications in real-world contexts. These two dimensions form the two-by-two matrix that teachers can use as a guide to map where a STEM activity is located in the matrix and how to move pieces of the curriculum to provide enhanced integration and applications. This matrix has been useful in the messaging about STEM teaching and learning, and provides room for teachers to exercise autonomy in deciding how best to flexibly design and enact STEM lessons depending on the nature of the activities, students' interest, and the availability of resources.

2. Insufficient protected time for STEM

The school curriculum is traditionally packed and crowded. A student's typical school day starts at about 0730 hours and ends at 1330 hours (primary schools) or at about 1430 hours (secondary schools and junior college). After the formal curriculum hours, many students stay behind in school for CCAs. Oftentimes, curriculum time that is intended for non-examinable subjects is used by the teachers of examinable subjects to catch up on their lesson delivery or to conduct remedial lessons for weaker students. In the case of the STEM ALP, schools have designated time within official school hours to ensure that the lessons committed to the STEM ALP lessons are not perceived as replaceable or optional. This is one of the reasons why STEM ALP has been implemented with great success in many Singapore schools. The "protected time" for STEM signals its importance and ensures that the curriculum will be implemented like other examinable subject lessons. In cases where STEM ALP is not an official program of the school, STEM has been incorporated into the subject-based lessons by making the subject the core, but bringing in ideas from within or outside the disciplines where appropriate.

3. Low levels of teacher readiness to embrace STEM learning

Most, if not all, teachers are not trained with an integrated STEM degree. Typically, it is the science teachers who are tasked to lead STEM teaching in schools. While most MOE teachers have two teaching subjects and several may cut across disciplines such as science and mathematics, the majority are trained in one discipline. As such, most teachers would have to move out of their comfort zone to work with teachers in other departments. The policy makers have foreseen teacher readiness as an area that requires support in order for STEM education to be successful. To support teachers to teach STEM, the MOE has funded STEM Inc., a section of the Science Centre Singapore to create STEM teaching resources, support teachers in teaching STEM lessons (e.g., by teaching, co-teaching, or mentoring teachers) to conduct STEM ALP lessons. In some cases, the teachers observe the instructors from STEM Inc. teach the STEM lessons; they learn and subsequently enact the lessons independently. This model of partnership is sustainable and empowering for teachers in getting them to be ready to teach STEM.

4. Low interest in STEM careers

Interestingly, students' readiness for STEM has never been an issue as STEM lessons are oftentimes applied and hands-on based. STEM is not an examinable subject, so STEM lessons are usually considered enjoyable. However, enjoyment may not necessarily translate into improved inclinations to subsequently pursue STEM higher degrees or careers. In an evaluation study conducted by Toh et al. (2022), Rasch analysis on the construct of STEM careers revealed that the students (research participants) recognized the benefits of taking up STEM careers, but it was not something that they would really like to do. Part of the reason, as alluded to from the findings, was that they have not received encouragement from their parents to take up STEM careers. To address this lack of cultural capital, teachers can inspire students to be more interested in STEM careers by themselves having some understanding of the STEM careers available. Such careers need not be limited to laboratory-based work that would not entice the younger generation who are more inclined to social interaction. In 2022, the Teacher Word Attachment Plus (TWA+) scheme was expanded from the previous TWA to offer industry attachment opportunities for teachers so that they can gain insider perspectives on industry happenings (STEM included) and return to the classroom to inspire their students.

5. Conflicting assessment demands for STEM learning

The topic of assessment is always brought to the table in high-stakes examinations economies that rely heavily on standardized instruments for accountability. It is true that the current state of STEM education research and teaching focuses on curriculum design and implementation, and there is much less less dialogue about assessment. The reason is simple – STEM activities are diverse and hence there are no universal content-based instruments that would fit every STEM activity. Even the same STEM lesson package can be conducted in a variety of ways, and many different approaches can be adopted. This flexibility is interesting to students but uncomfortable for teachers who seek convenient and standardized tools that they can administer to gather evidence of students' learning. However, teachers and school leaders must understand that the intention of STEM was not to create another examinable subject. STEM emerged from the traditional disciplines to address the limitations of monodisciplinary doing and thinking that can be clearly bounded by topic. For example, chemistry may be divided into organic chemistry, inorganic chemistry, analytical chemistry, and physical chemistry. STEM is intentional and purposeful in tearing down these pseudo-boundaries and distilling the best ideas to problem-find, problem-solve, improve existing solutions, and imbue humanistic values. Conventional paper-and-pencil assessments that examine content understanding becomes limited in STEM learning contexts. That is why STEM is not an examinable subject in the Singapore curriculum. Students can demonstrate what they understand through in-situ oral viva, presentations, built artefacts, and so on. An assessment rubric that is customized for each activity and which examines students' demonstration of certain knowledge and practices may be captured in holistic or analytic rubrics. Table 2 shows an example of a rubric adapted from Hu and Adey (2002) and Crismond and Adams (2012) that was used to access the level of creativity of students' answers. The use of rubrics, as opposed to marking schemes, allows evidence of students' learning to be captured in more than one way.

Table 2 Example of a rubric for assessing creativity

Traits	Criteria	Comments/Remarks
Originality	1. Able to raise problems/ideas/methods of representation/ways to use materials provided during discussion	
	2. Able to articulate reasons for the problems/ideas/methods of representation/ways to use materials provided being useful/novel	
	3. Able to add value by going beyond the requirements of the problem statement	
Fluency	1. Able to generate more than X problems/ideas/methods of representation/ways to use materials provided (includes those not acted upon)	
	2. Able to facilitate discussion that leads to the group raising more ideas (idea of leading the others towards being more fluent)	
	3. Able to set aside current idea to explore other ideas; willing to consider different options	
Flexibility	1. Able to identify problems/areas to focus on during the activity	
	2. Able to generate ideas (includes those not acted upon)	
	3. Able to represent problems/ideas in different modes (at least two of the following: verbal, textual, diagrammatic)	
	4. Able to use the materials provided in more than one way	

Source: Lee & Tan, 2022.

6. Rigid traditional structures of STEM in higher education

Another major issue in STEM education is the reluctance of universities to change. Oftentimes, the universities do not transform fast enough to meet the ever-changing demands of industries. In the recent decade, many companies in the private sector have undergone digital transformations to infuse artificial intelligence to improve operations. However, private industries are confronted with manpower crunches as they could not find sufficiently skilled graduates. They also face competition with big tech companies in hiring computer engineers (Kurohi, 2022). The Minister for Education, Mr. Chan Chun Sing, recently underscored the need for universities to work harder in connecting with the world, local communities, and industries (Ng, 2022). At NTU, the Promotion of Women in Engineering, Research and Science (POWERS) is one specific program that actively promotes gender diversity in STEM careers. Much more can be done at the degree program level. The APEC report by Teo and Sattar (2021) detailed the current status of STEM education in higher education and made recommendations to create more integrated STEM and gender-inclusive degree programs at the universities.

Conclusion

Singapore's education system has achieved great success in disciplinary science and mathematics education in the last 56 years since its independence in 1965. Singapore society has benefitted greatly from excellent disciplinary science and mathematics education. Moving forward, there will be a greater need to further develop and grow disciplinary science and mathematics education to include aspects of integrated STEM learning. Based on the trend of a large number of job roles requiring technological or mathematical skill sets, curricula related to technology such as computational thinking and tinkering with codes could be emphasized in schools. Instead of making computing a compulsory part of K-12 education, Singapore has adopted a stance to create interest in computing among even younger children through a range of age-appropriate programs (Seow et al., 2019). The early exposure to technological ideas could be one way to build STEM-related competencies from a young age and to allow a longer runway for the development of interests.

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Status and Trends of STEM Education in Sweden

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Abstract

STEM education in Sweden exists for students from their initial engagement with compulsory education at the age of 6 and is mandatory and cohesive for all students until they enter upper secondary level. The importance of STEM education is highlighted through the impact of STEM on the Swedish economy and can be further seen through government investment in STEM-related research activity. The aim of this chapter is to contextualize STEM education in the Swedish pre-college education system, and to discuss associated trends and issues which have emerged. The chapter includes an overview of the Swedish education system, noting when and where students make decisions on what they will study. This is followed by a description of some of the available STEM-related activities for students which complement their formal education. Next, trends in how Sweden has performed in related international assessments (PISA and TIMSS) are presented with a breakdown of student post-secondary education employment and further study demographics. The chapter concludes with commentary on current STEM education reform, and a presentation of some of the current trends and issues facing STEM education in Sweden which predominantly relate to a teacher supply shortage, gender differences in performance and STEM uptake, and the refinement and updating of STEM education provision in response to societal needs.

Keywords: STEM economy, Swedish STEM education, Swedish compulsory education, trends and issues in STEM education in Sweden

Introduction

Like most countries, Sweden's STEM sector accounts for a large portion of its economy. Sweden's labor force first exceeded 5 million people in 2017, and the most recent OECD statistics (2022) indicate that in 2020 the total labor force in Sweden was approximately 5.064 million people from a population of approximately 10.35 million people. Table 1 provides a breakdown of the 2020 Swedish labor force employment activity according to the major divisions of the International Standard International Classification (ISIC) and shows that while the majority of workers are employed in the Health and Education sectors (of which many could be engaged in STEM-related activities), a significant proportion are employed in areas such as the mechanical, manufacturing, construction, and information technology sectors, or are engaged in other professional, scientific, or technical activities. To take one specific example, the employers' organization Teknikföretagen (the Association of Swedish Engineering Industries) has 4,200 member companies employing over 300,000 people in Sweden alone and many more abroad. Their member companies, of which Volvo, Atlas Copco, Tetra Pak, Ericsson, and Scania are some of the largest, further account for approximately a third of Sweden's total exports. 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.

Table 1 Employment by activity in Sweden in 2020

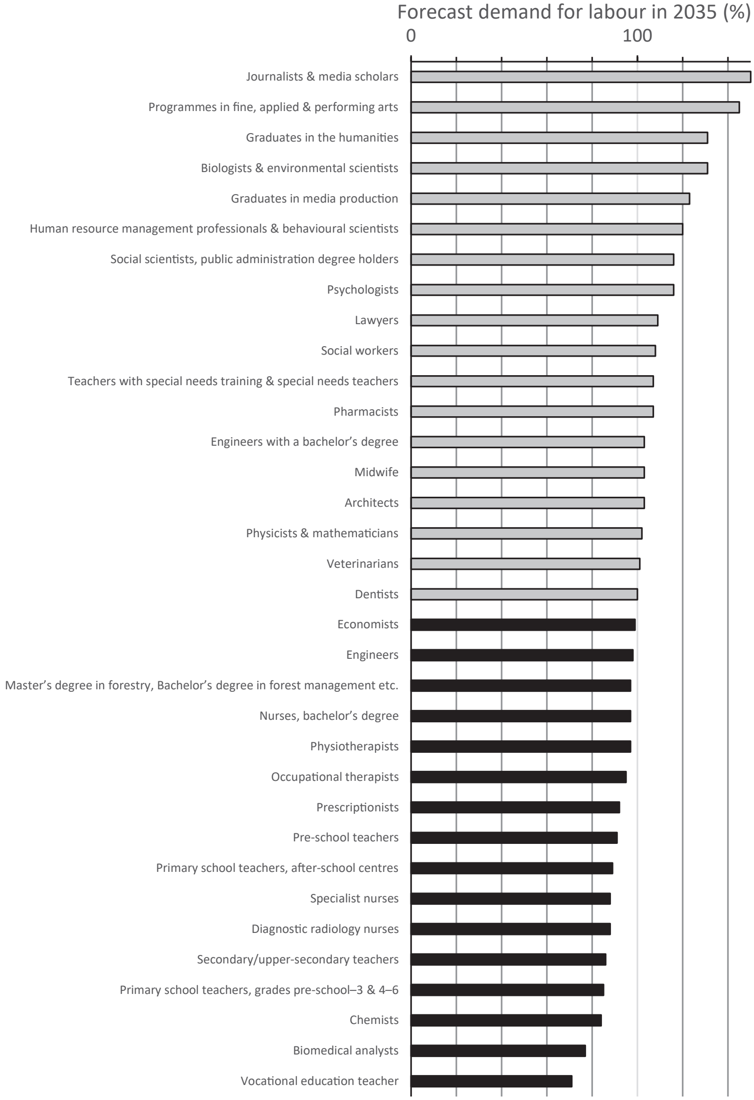
Employment Activity	Persons (1000's)
Human health and social work activities	757.775
Education	567.9
Wholesale and retail trade, repair of motor vehicles and motor-cycles	562.25
Manufacturing	500.525
Professional, scientific and technical activities	450.675
Public administration and defense, Compulsory social security	368.7
Construction	352.675
Information and communication	269.9
Transportation and storage	232.75
Administrative and support service activities	221.55
Accommodation and food service activities	140.1
Arts, entertainment and recreation	130.85
Other service activities	126.425
Financial and insurance activities	107.55
Agriculture, hunting and forestry	86.95
Real estate activities	81.875
Electricity, gas, steam, and air conditioning supply	31.975
Water supply, sewerage, waste management and remediation activities	25.5
Mining and quarrying	10.2

Source: Organisation for Economic Co-Operation and Development, 2022.

Beyond understanding the current employment activity of the Swedish labor force, the Swedish Higher Education Authority (2021) in association with Statistics Sweden (2021) forecasted the national demand for higher education graduates in 2035. Figure 1 illustrates the results of their forecast model. The main areas which are predicted to not meet the 2035 labor force demand relate to economics, engineering, forestry, science and health (general, specialist, and diagnostic radiology nurses, physiotherapists, occupational therapists, pre-scriptionists, chemists, and biomedical analysts), and education (pre-school, primary school, after school, lower and upper secondary level, and vocational teachers). The majority of these areas of demand are STEM related, and while there are several STEM occupations which are forecast to exceed the 2035 demand such as biologists, environmental scientists, and engineers qualified to Bachelors (International Standard Classification of Education [ISCED] level 6) level, the majority of occupational areas forecast to have graduate numbers exceeding the 2035 demand are not STEM related. In other words, in the context of future workforce needs, there is a need for an increased emphasis on STEM education in Sweden relative to current trends.

With respect to reacting to labor force needs, while higher education institutions have considerable autonomy, the government has overall responsibility for higher education with funding allocation being a dominant way of having an impact. For example, in response to the ongoing and forecast labor demand, the Swedish government have been providing extra funding to higher education institutions for teacher education programs since 2015 (Swedish Higher Education Authority, 2021).

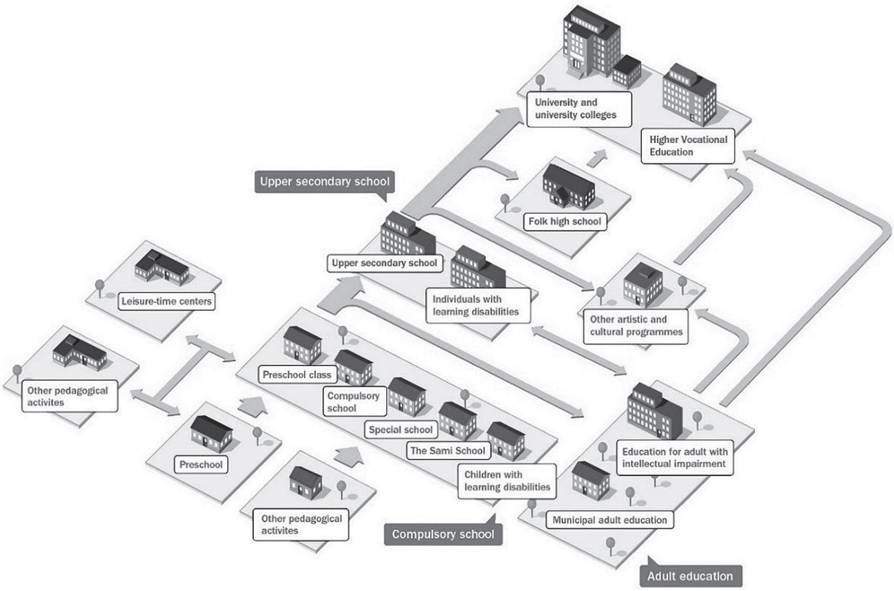
Figure 1 Estimated number of graduates relative to demand for labor (%) for different education groups in 2035



Note: Grey bars indicate educational groups forecast to meet or exceed the required demand in 2035 and black bars indicate educational groups forecast not to meet the required demand in 2035.
Source: Statistics Sweden, 2021; Swedish Higher Education Authority, 2021.

Prior to entering the labor force, Swedish students' progress through an education system which consists of a series of stages. This is illustrated in Figure 2 and will be explained in more detail in the next section. For the majority of students it consists of Förskoleklass (preschool, ages ≈ 6-7), a three-stage Grundskola (compulsory school, ages ≈ 7-16), and Gymnasium (upper secondary school, ages ≈ 16-19), prior to students entering higher level education where they can earn Diplomas as well as Bachelor, Master, Licentiate, and Doctoral Degrees. As with higher education, it is the Riksdag (the Swedish national legislature or parliament) and the government who are responsible for the curriculum and what students learn in school (Skolverket, 2022g). In particular, the Swedish government is responsible for national curricula. The compulsory school curriculum in Sweden is cohesive in that all students follow the same curriculum and all subjects offered are mandatory. The curriculum is written by Skolverket, the Swedish National Agency for Education, on behalf of the government. This process sees Skolverket initially inviting a group of experts to prepare an initial draft of subject-level curriculum information such as knowledge requirements for different grade levels. To take an example, members of the Swedish Centre for School Technology Education (CETIS) in Linköping University, among other experts, would be involved at this stage for the Technology subject curriculum. Following this, the curriculum documentation then goes through a series of review rounds, initially by stakeholders such as higher education institutions and professional associations with a final open review where anyone can comment. While it is the Riksdag and government who are ultimately responsible for the curriculum, school principals are responsible for the students achieving the curricular aims.

Figure 2 The Swedish education system



Note: For clarity, the "compulsory school" stage includes five types of school of which one is called "compulsory school."
Source: Skolverket, 2022d.

The Status of STEM Education

The Swedish Compulsory Education System and the Position of STEM Education

Many countries describe pre-college education as K-12, and this is similar in Sweden; however, kindergarten is referred to as preschool and it is more common to use the terminology of years 1-12 rather than grades 1-12 This section will discuss the Swedish education system up to year 12 to contextualize STEM education at this stage, but will use the terminology more typical to

Sweden.

As mentioned, in Swedish compulsory education all students generally study every subject. Unlike many other countries where there are optional or elective subjects, this is not really the case in Sweden at this level of education. There are optional subjects in that students can choose to study a third language in addition to Swedish and English or not, which could be a modern language such as Spanish, Mandarin, or French, or sign language. There can also be some minor differences in how subjects are categorized for individual students, particularly with respect to the study of native languages. For example, while all students must learn Swedish, it is a native language for some and a second language for others. As the system has little in the way of optional subjects, all compulsory school students receive the same STEM education as each other – at least at the written curriculum level.

For children, formal education typically begins in Autumn in the year when they turn six years old. At this stage, most children attend preschool. According to the most recent national statistics, 86% of Swedish 1- to 5-year-olds attended preschool during 2021 (Skolverket, 2022c). There is a national curriculum for preschool (Skolverket, 2018b) which embraces a holistic interdisciplinary approach to learning, fostering creativity, curiosity, interest, and the joy of learning. Specifically, the aim of preschool education in Sweden is "to further pupils' fantasy, experiences and ability to learn, in co-operation with others, through play, movement and creation using aesthetic forms of expression as well as explorative and practical working methods" (Skolverket, 2018b, p. 19). The core content of the pre-school curriculum is outlined under the following areas:

- Language and curriculum
- Creative and aesthetic forms of expression
- Mathematical reasoning and forms of expression
- Nature, technology, and society
- Games, physical activities, and outdoor excursions

The closest of these areas to STEM are those of "creative and aesthetic forms of expression," "mathematical reasoning and forms of expression," and "nature, technology, and society." To give an example of the nature of STEM learning in pre-school, example prescribed core content includes[1]:

- Creative and aesthetic forms of expression
  - Different materials, tools and technologies for creating and expressing oneself.
  - Interpret and discuss the content and message in different forms of aesthetic expression.
  - Digital tools for presenting different forms of aesthetic expression.
- Mathematical reasoning and forms of expression
  - Simpler mathematical reasoning to explore and analyse problems and ways to solve problems.
  - Natural numbers and their characteristics and how they can be used for counting and order. Part of a whole and part of a quantity.
  - Mathematical concepts and different forms of expression to explore and describe space, time, form, direction, pattern, time and change.
- Nature, technology, and society
  - Different ways to explore phenomena and relationships in nature, technology and society, for example through observations, measurements and discussions of findings. How pupil relevant phenomena and relationships can be described, for example with words and pictures or simpler tables and diagrams.
  - Democratic values and principles, in situations that are familiar to the pupils. How common decisions can be made and how conflicts can be handled constructively.
  - Chemical and physical phenomena that are familiar to the pupils, for example the transition of ice to water, friction and visible astronomical phenomena.

1 Full curricular specifications are available in English from Skolverket (2018b) at https://www.skolverket.se/download/18.31c292d516e7445866a218f/1576654682907/pdf3984.pdf

- Some common technical solutions ordinarily occurring in pupils' lives, how they are designed, work and could be improved.
- How different everyday choices people make can contribute to sustainable development.

Following preschool most students enter compulsory school (Figure 2). Compulsory school consists of three three-year stages including lågstadiet (primary school, years 1–3), mellanstadiet (middle school, years 4–6) and högstadiet (high school, years 7–9). Compulsory school is also governed by a national curriculum provided by Skolverket (2018b)[2]. The curriculum is divided into five sections but should be read as a whole in order to fully grasp the purpose of Swedish compulsory education. The sections include:

1. Fundamental values and tasks of the school
2. Overall goals and guidelines
3. Preschool class
4. School-age educare
5. Syllabuses

The subjects offered in compulsory school, as well as the hours of instruction, are listed in Table 2. For each subject, the "syllabuses" section of the curriculum lists the aims of the subject, the abilities which the subject should give the students an opportunity to develop, topics and "core content" (which is presented as a series of learning outcomes) for each of the three stages (years 1-3, years 4-6, and years 7-9), and knowledge requirements (assessment criteria) for awarding students either A, B, C, D, or, E grades (Grade F is a failing grade) at the end of years 6 and 9. Within each subject, the topics are generally but not always the same for each stage, but where similar the core content listed within each topic changes. To give an example, for the Mathematics

2 Please note that the national curriculum is currently being revised but is not publicly available at the time of writing this chapter. The subjects will remain the same, but some content has been changed.

subject one of the topics is "relationships and change" (which, as the shortest topic, is used here for demonstration purposes). This is a consistent topic for each stage, but the core content changes as follows:

- Years 1-3
  - Different proportional relationships, including doubling and halving.
- Years 4-6
  - Proportionality and percentage and their relationship.
  - Graphs for expressing different types of proportional relationships in simple investigations.
  - The coordinate system and strategies for scaling coordinate axes.
- Years 7-9
  - Percent as a means of expressing change and rate of change, and also calculations using percentages in everyday situations and in situations in different subject areas.
  - Functions and linear equations. How functions can be used, both with and without digital tools, to examine change, rate of change and relationships.

Table 2 Compulsory school subjects and associated hours of instruction

Subject	Lågstadiet	Mellanstadiet	Högstadiet	Total
Art	50	80	100	230
English	60	220	200	480
Home and consumer studies	36		82	118
Physical education and health	140	180	280	600
Mathematics	420	410	400	1,230
Language selection (modern language; mother tongue language; Sami; sign language)		48	272	320
Music	70	80	80	230
Science subjects	143	193	264	600
Biology		55	75	
Physics		55	75	

Table 2 (continued)

Subject	Lågstadiet	Mellanstadiet	Högstadiet	Total
Chemistry		55	75	
Society orientated subjects	200	333	352	885
Geography		70	75	
History		70	75	
Religion		70	75	
Civics		70	75	
Crafts	50	140	140	330
Swedish or Swedish as a second language	680	520	290	1,490
Technology	47	65	88	200
The student's choice				177

Note: Total hours = 6,890

STEM education is embedded in several subjects, however it is predominantly in the subjects of Mathematics, Technology, Sloyd (Crafts), and the science subjects (Biology, Physics, and Chemistry), which are all mandatory from grade 1 to grade 9. To outline what STEM education looks like through these subjects, the core content topics are as follows:

- Mathematics (Years 1-9)
    - Understanding and use of numbers
    - Algebra
    - Geometry
    - Probability and statistics
    - Relationships and change
    - Problem solving
- Science (Years 1-3)
    - Seasons of the year in nature
    - Body and health
    - Force and motion
    - Materials and substances in our surroundings

    - Narratives about nature and science
    - Methods and ways of working
- Biology (Years 4-9)
    - Nature and society
    - Body and health
    - Biology and world views
    - Biology, its methods and ways of working
- Physics (Years 4-9)
    - Physics in nature and society
    - Physics in everyday life
    - Physics and world views
    - Physics, its methods and ways of working
- Chemistry (Years 4-9)
    - Chemistry in nature
    - Chemistry in everyday life and society
    - Chemistry and world views
    - Chemistry, its methods and ways of working
- Technology (Years 1-9)
    - Technological solutions
    - Working methods for developing technological solutions
    - Technology, man, society and the environment
- Sloyd (Crafts: Years 1-9)
    - Materials, tools and techniques used in crafts
    - Working processes in crafts
    - Aesthetic and cultural expressions in crafts
    - Crafts in society

The minimum number of hours of instruction for each subject a student can expect to be taught is regulated nationally (Skolverket, 2022f). This is detailed for each subject in Table 2. Of the 6,890 total guaranteed hours of compulsory school, 1,230 hours are allocated to Mathematics, 600 are allocated to science education, 200 are allocated to Technology, and 330 are allocated to Sloyd (Crafts). In other words, there are 2,360 hours (34.25%) directly related to STEM subjects, and there would be more STEM-related content in other subjects such as Physical Education and Health, History, and Geography. For science education, as described above, the core content for years 1-3 is identical for each of the three subjects (as all students study each subject, this relates to a singular science curriculum for years 1-3). From year 4, students receive dedicated minimum hours of instruction in each of Biology, Physics, and Chemistry. For example, for Years 4-6, students should receive 193 hours of science instruction, with a minimum of 55 hours for each of the three subjects. The remaining 28 hours can be freely distributed by the school between the three subjects. A similar system is in place for years 7-9, with 264 total hours of science instruction and a minimum of 75 hours of instruction per subject (Skolverket, 2022f). While this is nationally regulated, each school has autonomy in the delivery of each subject from a pedagogical perspective. Provided teachers work within the curricular regulations and address the core content in the syllabi, they can structure the organization of learning however they wish.

As shown in Figure 2, running in parallel to compulsory school are Sami schools, special schools, and schools for children with learning disabilities. The curriculum for Sami schools is the same as what has been described thus far. Sami schools are state-owned, and access is open only to children whose parents identify as Sami[3]. There is a different curriculum for students who attend special schools or schools for children with learning disabilities. This is also provided by Skolverket (2018a) and follows the same structure as the compulsory school curriculum; however, while the topics within syllabi are broadly similar, there is different core content within topics. The main struc-

3 The Sami are "an indigenous people who inhabit Sápmi, their preferred name for Lapland, and adjacent areas of northern Norway, Sweden, and Finland as well as the Kola Peninsula of Russia. They are speakers of the Sami languages, which are endangered" (Encyclopaedia Britannica, 2022).

tural difference is that in the compulsory school curriculum science education is divided across three discrete syllabi (Biology, Physics, and Chemistry) and society orientated education is divided between four (Geography, History, Religion, and Civics). In the curriculum for special schools, these groups are merged into single syllabi known as "Science subjects: biology, physics, and chemistry" and "Society orientated subjects: geography, history, religion, and civics" respectively (please note these are the authors' own translations from a Swedish curriculum document). With regards to STEM, unlike science education, both Mathematics and Technology are discrete mandatory subjects in special schools similar to how they are offered in compulsory schools.

National Assessment in Swedish Compulsory School

Ultimately, compulsory school teachers assess their own students with the first formal assessment taking place in year 6 and the second in year 9 (informal assessment for formative purposes is more frequent). Teachers award grades to their own students based on a holistic judgement of their performance to date in each subject (Erickson & Tholin, 2022). To support teachers in the assessment of their students there are national tests in some subjects (for full details see Skolverket, 2022b). Over a period of 1.5 to 2.5 years, national tests are designed by several Swedish universities and colleges and are tested by both teachers and students. In year 3 students sit national tests in Mathematics and Swedish (this includes students taking Swedish as a first or second language). In year 6, national testing occurs in the subjects of Mathematics, Swedish, and English. In year 9, there are again national tests in Mathematics, Swedish, and English, but there are also national tests in the science subjects (Biology, Physics, and Chemistry) and social education (Geography, History, Religion, and Civics). For these, schools randomly receive tests for one subject in each category. For example, year 9 students in one school may take national tests in Mathematics, Swedish, English, Physics (randomly received science test) and Geography (randomly received society-orientated subject), whereas year 9 students in another school may take national tests in Mathematics, Swedish, English, Biology (randomly received science test) and History (randomly received society-orientated subject). With regards to STEM, at least in terms of the subjects very closely related to STEM, there are therefore national tests in Mathematics, students will sit one national test in one of Biology, Physics, or Chemistry, and there are no national tests in Technology or Sloyd (Crafts).

Like the school curriculum, Skolverket is also responsible for national statistics pertaining to education. An example of the type of data available is provided in Table 3 (Skolverket, 2022c). Table 3 describes the average grade point average for all students and is broken down for male and female students for all subjects. Note that these data relate to the grades awarded by teachers to their own students, not results of national tests. Such data are available by year, and at different levels such as results based on school type or by municipality. Interestingly, what Table 3 shows is that in the academic year 2020/21 (the most recent data available at the time of writing this chapter), girls outperformed boys in all subjects in Year 6, and in all subjects except for Physical Education and Health in year 9. Unlike many other countries which see male students outperforming female students in most STEM areas, this is not the case in Swedish compulsory education.

Table 3 Average grades for Swedish year 6 and year 9 students from the 2020/21 academic year

Academic year 2020/21	Year 6						Year 9					
Subject	Number of students			Average grade point average			Number of students			Average grade point average		
	All	Female	Male	All	Female	Male	All	Female	Male	All	Female	Male
Art	117,345	57,066	60,279	14.0	15.4	12.6	114,143	55,843	58,300	14.9	16.3	13.5
English	120,451	58,502	61,949	14.2	14.4	14.1	115,368	56,238	59,130	14.6	14.9	14.4
Home and consumer studies	115,826	56,358	59,468	13.9	15.0	12.8	113,914	55,614	58,300	14.8	16.0	13.7
Physical education and health	119,884	58,279	61,605	13.8	13.9	13.7	112,793	54,813	57,980	14.6	14.5	14.7
Mathematics	120,542	58,530	62,012	12.8	12.8	12.7	115,404	56,245	59,159	12.5	12.7	12.4
Modern language (Student choice)	382	184	198	15.4	15.8	15.1	1,046	555	491	17.1	17.6	16.4
Modern language (Language choice)	105,047	52,242	52,805	14.1	14.9	13.3	82,014	42,053	39,961	14.3	15.1	13.4
Mother tongue	18,854	9,544	9,310	14.2	14.7	13.7	16,936	8,712	8,224	16.5	17.0	16.0
Music	119,151	58,018	61,133	14.0	14.8	13.2	113,349	55,383	57,966	14.9	15.7	14.1
Science subjects (blocks)	13,805	6,727	7,078	13.5	14.1	12.9						
Biology	105,785	51,425	54,360	13.2	13.9	12.5	112,202	54,930	57,272	13.5	14.3	12.8
Physics	105,685	51,382	54,303	13.0	13.4	12.5	111,007	54,296	56,711	13.3	13.8	12.8
Chemistry	105,495	51,289	54,206	12.8	13.4	12.3	110,921	54,300	56,621	13.2	13.8	12.6
Socially orientated subjects (blocks)	12,545	6,076	6,469	13.6	14.2	13.0						
Geography	106,909	51,990	54,919	13.2	13.7	12.6	113,269	55,339	57,930	13.9	14.6	13.2
History	106,989	52,044	54,945	13.1	13.7	12.5	113,316	55,344	57,972	14.0	14.6	13.4
Religion	106,851	51,987	54,864	13.2	14.0	12.5	113,258	55,412	57,846	13.9	14.8	13.1
Civics	106,917	52,001	54,916	13.2	13.9	12.6	113,521	55,455	58,066	13.8	14.5	13.1
Crafts	119,580	58,174	61,406	13.7	14.7	12.7	113,728	55,557	58,171	14.9	15.9	14.0
Swedish	103,156	50,460	52,696	13.5	14.8	12.3	99,172	48,939	50,233	14.4	15.5	13.3
Swedish as a second language	17,425	8,100	9,325	8.4	9.5	7.5	16,313	7,356	8,957	9.1	9.9	8.5
Sign language	37	14	23	14.6	15.0	14.3	88	45	43	14.5	17.2	11.5
Technology	117,448	57,125	60,323	13.3	13.8	12.8	112,622	54,889	57,733	14.0	14.6	13.5

Note: The average grade point average is calculated for students who have received a grade of A-F. Grade F gives 0 points, E gives 10 points, D gives 12.5, C gives 15, B gives 17.5 and A gives 20 points.

Progression to Upper Secondary Level Education

Following compulsory school, all students have a right to progress to upper secondary level education, known as "gymnasium" (Figure 2), which is equivalent to years 10-12. Student performance in year 9 of compulsory school relates to eligibility for courses in upper secondary education. Students typically begin upper secondary school at the age of 16 and complete it at the age of 18, and as before a formal curriculum is provided by Skolverket (2013). Structurally, upper secondary education in Sweden differs greatly from compulsory education as students specialize in their learning at this stage.

There are 18 different national programs offered by upper secondary level educational providers, which can be either private or public. The programs are offered across two strands, a vocational strand (12 programs) and a higher education preparatory strand (8 programs). A full list of the available programs is offered in Table 4. Students who complete a program in the vocational strand should be prepared for working life and achieve basic eligibility to higher education. In other words, they would be eligible to attend higher education, but may not have achieved some specialist requirements to study in certain higher education courses. Students who complete a higher education preparatory program should be prepared at the end to enter higher education (Skolverket, 2011).

Table 4 Vocational and higher education preparatory programs offered at upper secondary level education in Sweden

Vocational strand programs	Higher education preparatory strand programs
Building and Construction	Arts
Business and Administration	Business Management and Economics
Children and Recreation	Humanities
Electricity and Energy	Natural Science
Handicraft	Social Science

Table 4 (continued)

Vocational strand programs	Higher education preparatory strand programs
Health and Social Care	Technology
Hotel and Tourism	
HVAC (heating, ventilation, and air conditioning) and Property Maintenance	
Industrial Technology	
Natural Resource Use	
Restaurant Management and Food	
Vehicle and Transport	

As mentioned, eligibility to upper secondary level programs is based on year 9 grades. For any program, students must have received a passing grade in Swedish (as a native or second language), English, and Mathematics. In addition to this, for each of the vocational strand programs students must have achieved a passing grade in any further five subjects, therefore receiving a passing grade in at least eight subjects. For the programs in the higher education preparatory strand, students must earn further passing grades in at least nine other subjects, and therefore pass at least 12 subjects in total. In addition, there are program-specific requirements for all but the Arts program. To enter the Business Management and Economics, Social Science, or Humanities programs, four of these additional nine passing grades must be in the society-orientated subjects (Geography, History, Religion, and Civics). To enter the Natural Science or Technology programs, three of these additional nine passing grades must be in the science subjects (Biology, Physics, and Chemistry). It is interesting to note that to become eligible for the Technology program at upper secondary level a student does not require a passing grade in the compulsory school Technology subject. For students who do not meet these eligibility requirements, there are five introductory programs which aim to prepare students for the labor market, or for entry to one of the aforementioned upper secondary level programs or another form of education (Skolverket, 2011).

These include:

1. Individual alternative
2. Language introduction
3. Preparatory education (International Baccalaureate)
4. Program-oriented individual options
5. Vocational introduction

All programs in upper secondary education have specializations. Here, the Technology program from the higher education preparatory strand will be used as an example (Skolverket, 2022e). There are five specializations within this program from which students must choose one. For this program, the specializations they can choose from are (authors own translation):

1. Design and product development
2. Information and media technology
3. Production technology
4. Community building and environment
5. Engineering science

There are three categories of subjects a student takes within a program including subjects common to all upper secondary level students, subjects common to all upper secondary level students in a specific program, and subjects common to all upper secondary level students in a specific specialization. For the Technology program, the subjects offered are structured as follows (Skolverket, 2022e):

- Upper secondary level common subjects
    - English
    - History
    - Sports and health
    - Mathematics
    - Religion
    - Civics
    - Swedish (as a native or second language)

- Program-specific subjects
    - Physics
    - Cheistry
    - Technology
- Specialization-specific subjects
    - Design and product development
        - Art
        - Computer aided design (CAD)
        - Design
        - Construction
    - Information and media technology
        - Computer and communication technology
        - Programming
        - Web development
    - Production technology
        - Mechatronics
        - Production knowledge
        - Production equipment
    - Community building and environment
        - Architecture
        - Sustainable society
        - Community building
    - Engineering science
        - Physics
        - Mathematics
        - Technology

Other subjects such as Animation, Electronics, Philosophy, and Psychology may also be offered as part of this specialization.

Skolverket (2022c) also provides statistics on the number of students who enter each of the three strands (vocational, higher education preparatory, and introductory), and which programs they enter within each strand. Table 5 provides these data for 2021 at the strand level. The large majority (60.4%) of Swedish students enter higher education preparatory programs, and these programs are entered more by females (66.3%) than males (54.9%). In contrast, much lower percentages of students enter vocational programs (29.2%) and introductory programs (10.3), and males are more likely than females to enter programs in these strands.

Table 5 Swedish upper secondary school strand demographics in 2021

Strand	Total Students	Total Students (%)	Male Students (%)	Female Students (%)
Higher Education Preparatory	218623	60.4	54.9	66.3
Vocational	105618	29.2	33.7	24.4
Introductory	37432	10.3	11.3	9.3

Table 6 provides a more detailed view of which programs students typically enter. The most in demand programs are the Social Science and Business Management and Economics programs - not STEM programs. These accounted for 32.2% of upper secondary students in 2021. These were followed by the STEM-related Natural Science and Technology programs which accounted for 21.2% of upper secondary level students in 2021. Based on a crude classification of programs as STEM-related by the authors based on the program title (and this is certainly debatable in a number of instances, see Table 6), approximately 42.2% of upper secondary level students in Sweden in 2021 were in STEM-related programs.

Table 6 Swedish upper secondary school program demographics in 2021

Program	Strand	Percentage of Students
Social Science	Higher Education Preparatory	17.6
Business Management and Economics	Higher Education Preparatory	14.6
Natural Science*	Higher Education Preparatory	12.6
Technology*	Higher Education Preparatory	8.6
Arts	Higher Education Preparatory	5.7
Electricity and Energy*	Vocational	4.4
Building and Construction*	Vocational	3.8
Vehicle and Transport*	Vocational	3.8
Individual alternative	Introductory	3.4
Children and Recreation	Vocational	3
Natural Resource Use*	Vocational	2.9
Business and Administration	Vocational	2.8
Health and Social Care	Vocational	2.7
Language introduction	Introductory	2.4
Program-oriented individual	Introductory	2.2
Vocational introduction*	Introductory	2.2
Handicraft*	Vocational	1.7
Industrial Technology*	Vocational	1.2
Restaurant Management and Food	Vocational	1.2
HVAC (heating, ventilation, and air conditioning) and Property Maintenance*	Vocational	1
Preparatory education (International Baccalaureate)	Introductory	0.9
Hotel and Tourism	Vocational	0.6
Humanities	Higher Education Preparatory	0.5

Note: Crude author classification as STEM-related denoted by *

STEM-related Activities

In addition to engaging with STEM through formal education, there are many informal opportunities for young people in Sweden to participate in STEM-related activities. However, these are both many and are not organized through a centralized system. Many individual people can and have organized ad-hoc STEM-related summer camps for example, so providing details on all informal STEM-related activities would not be possible. Instead, details of three relatively large providers of STEM-related activities known to the authors outside of the formal school curriculum will be briefly described.

One way in which Swedish people can engage with STEM beyond formal schooling is through museums. One such museum is the National Museum of Science and Technology, or Tekniska, which attracts more than 300,000 visitors per year (Tekniska, 2022). The museum has a wide variety of exhibitions, including ones relating to carbon dioxide emissions, artificial intelligence, genome editing, computer gaming, mining, and a mathematical garden. Beyond the exhibitions which are open to the public, they also offer workshops tailored for schools. Currently, they offer eight such workshops:

1. Autonomous vehicles and programming with Spike
2. Sustainable vision: City
3. Spike – programming with Lego robots
4. Media program in the studio
5. MegaMind Funkis (a workshop specifically tailored to students with learning disabilities to explore their own creative ideas in a safe environment)
6. Power and movement
7. Strength and construction
8. The Mind Lab (a workshop specifically tailored to toddlers and children with learning disabilities to stimulate learning through play and social interaction)

Finally, Tekniska contributes to schools in other ways such as visiting schools whose students could not attend otherwise (for example, they have a mobile “programming in school” maker tour) and by offering competitions (such as a current one aimed as recycling plastics) in which students send their entries to the museum for review.

A second type of initiative are those organized by higher education institutions. Vetenskapens Hus (English translation: House of Science) is a resource developed in 2001 by KTH Royal Institute of Technology and Stockholm University with an aim of increasing students' knowledge of and interest in STEM (Vetenskapens Hus, 2020). Vetenskapens Hus has two buildings, one of which has well-equipped laboratories and the other which is centered around a botanical garden. Catering for approximately 80,000 visits by both compulsory and upper secondary school students each year, programs are provided for school students, teachers, and people undertaking work experience. A unique characteristic of Vetenskapens Hus is that visiting school students are met by university students who can act as role models and university faculty members. The connectivity with university lecturers and researchers means that programs offered are consistently updated to be state-of-the-art based on contemporary research activity. There are currently approximately100 programs offered for compulsory school students in the areas of mathematics, biology, physics, chemistry, and technology. For upper secondary school students, Vetenskapens Hus facilitates students working with researchers at KTH and Stockholm University on a group project. Current projects which students can apply to participate in include:

- Allelopathy – the secret war of plants (chemistry and biology)
- Gamma-ray bursts – the universe's most powerful explosions (physics and astronomy)
- Insect physiology and biomimicry (biology, physics, and technology)
- Cosmic radiation (physics)
- The basics of mathematics (mathematics)
- Nanocellulose – new bio-based materials from the forest (chemistry)
- Recycling of mobile phones (chemistry and technology)

Finally, there are many STEM-related summer camps offered to school students in Sweden. A non-profit organization called Hello World is one company which arranges these camps and has a specific emphasis on programming and learning to code (Hello World, 2022). They currently offer camps in two STEM areas. One of these is called “Hello Summer!” which is a digital-based summer camp which sees young people design digital creations using technologies of their choice from a library of software including Unity 3D, Minecraft, Space Studio, YouTube Studio, and Python. The second is called “Bootcamp x SPACE Academy” which is a collaboration between Hello World and SPACE Stockholm and is focused on game development and programming. In addition, they also offer a range of workshops on, for example, 3D modelling, graphic design, Scratch programming, entrepreneurship, Python, web design, and game design.

STEM Learning Assessment and Progression to Post-secondary Education

International assessment: PISA and TIMSS

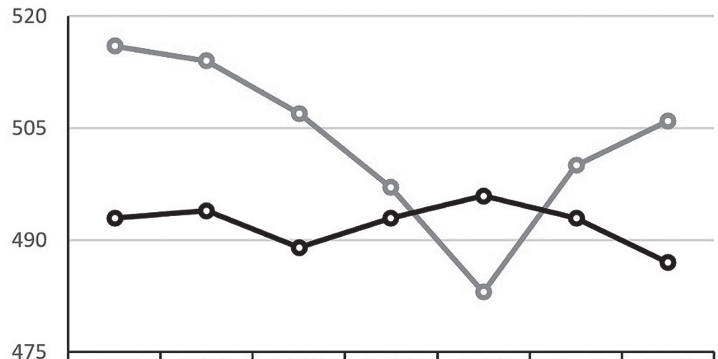
In addition to national tests, Sweden participates in a number of international tests. Two such tests are the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) tests. The most recent PISA report available for Sweden is from 2018 (OECD, 2019). In the report, trends in performance for reading, mathematics, and science are provided (Figure 3). With regards to performance, a summary of how Sweden has performed over time is also provided. Key points in this regard are:

- In 2018, Swedish students scored higher than average in all three areas.
- Approximately 13% of Swedish students were top performers in reading (OECD average ≈ 9%)
- Approximately 13% of Swedish students were top performers in mathematics (OECD average ≈ 11%)
- Approximately 8% of Swedish students were top performers in science (OECD average ≈ 7%)

There was a rapid decline in mean performance in 2012 in all three areas (Figure 3), however that has now been fully or almost fully recovered.

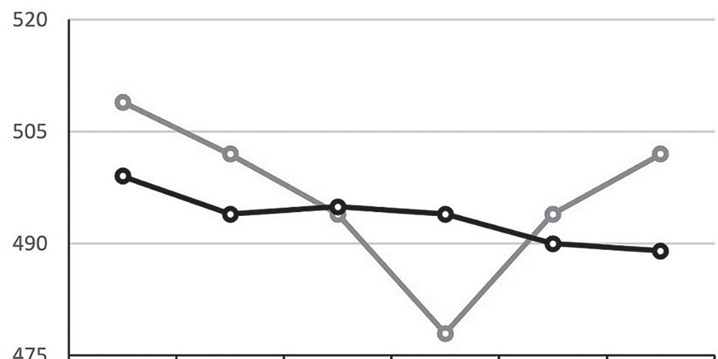
Figure 3 Trends in PISA results for Sweden in comparison to the OECD average

A: Reading



	2000	2003	2006	2009	2012	2015	2018
Sweden	516	514	507	497	483	500	506
OECD Average	493	494	489	493	496	493	487

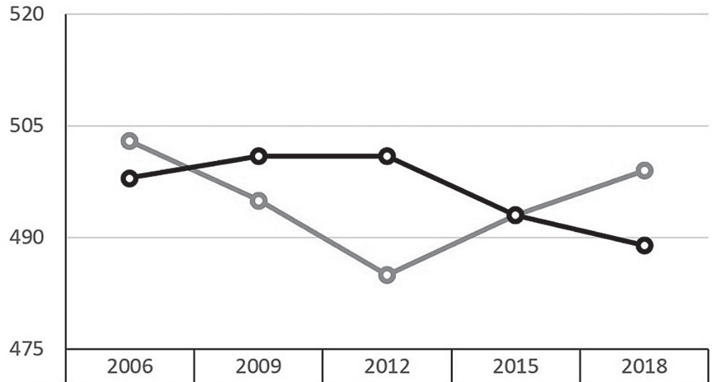
B: Mathematics



	2003	2006	2009	2012	2015	2018
Sweden	509	502	494	478	494	502
OECD Average	499	494	495	494	490	489

Figure 3 (continued)

C: Science

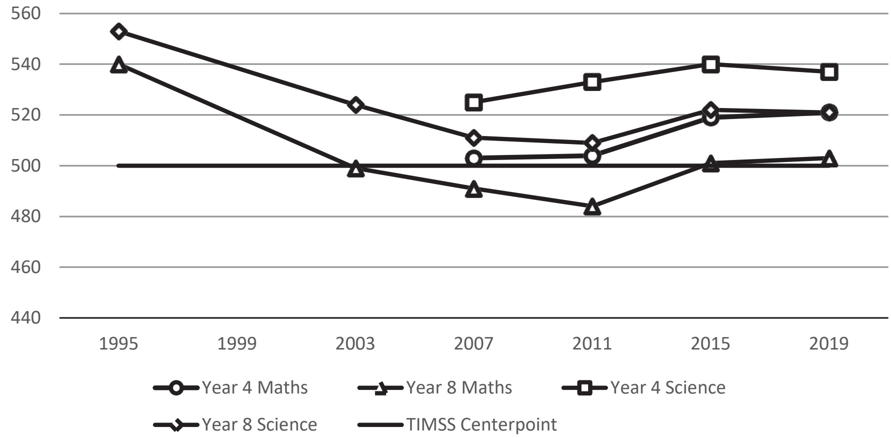


	2006	2009	2012	2015	2018
Sweden	503	495	485	493	499
OECD Average	498	501	501	493	489

Source: OECD, 2019.

Similar to PISA, Sweden tends to see above average performance in mathematics and science in the TIMSS test (International Association for the Evaluation of Educational Achievement, 2022). Since Sweden has participated in the TIMSS test it has always performed above average in year 4 mathematics and science and in year 8 science. Recently, it has been above average in year 8 mathematics as well. Two notable statistics are that within mathematics and science Sweden performs relatively more above average in year 4 than in year 8, and within year 4 and year 8 Swedish students perform on average higher in the TIMSS science tests than in the mathematics tests. In addition to the STEM-related activities beyond formal schooling which were previously discussed, a number of initiatives have been implemented in Sweden to improve mathematics and science achievement. These will be discussed in a later section, but tests such as PISA and TIMSS are used as indicators of the value of these initiatives (Axelsson, 2019).

Figure 4 Swedish performance in the Trends in International Mathematics and Science Study (TIMSS) tests since 1995



Progression to post-secondary education

Skolverket (2022c) provides statistics on the activities of students' post-secondary education. The most recent data come from 2019 and describe the status of students one year after they completed upper secondary level education in the academic year 2017/18. One interesting piece of data they provide describes how many students enter employment or pursue further education (see Table 7). Following upper secondary education, students on both vocational and higher education preparatory programs are more likely to enter employment than to pursue further study; however, there is a significant difference between both strands. Approximately 77% of students on a vocational program enter employment after upper secondary education, whereas only about 45% of students on a higher education preparatory program enter employment and do not pursue further study. In contrast, relatively few students (approximately 17%) on vocational programs pursue further study in comparison to those on higher education preparatory programs (approximately 52%).

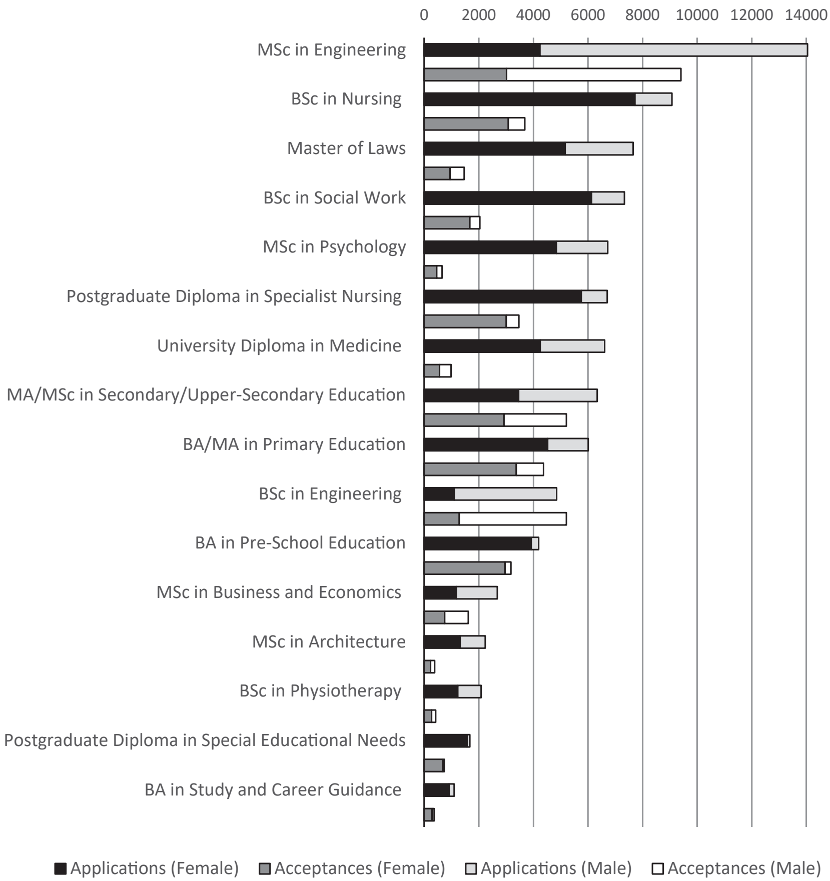
Table 7 Swedish student post-secondary education activity based on upper secondary education program type

	Vocational program (*n* = 31,453)		**Higher education preparatory program (*n* = 60,699)**	
	Female (*n* = 12,817)	Male (*n* = 18,636)	Female (*n* = 32,177)	Male (*n* = 28,522)
Employed	72.4%	80.7%	44.6%	45.4%
University studies	6.9%	2.0%	37.0%	34.9%
Other studies	16.4%	11.3%	16.3%	16.3%
Neither employed nor registered as a student	4.3%	6.0%	2.1%	3.4%

Where Skolverket provides these high level statistics, the Swedish Higher Education Authority provides more specific data on post upper secondary school activity with regard to higher education enrolment (Swedish Higher Education Authority, 2021). To give context to these data, it is important to note that there are three categories of qualification in Sweden, all of which hold the same academic status – general qualifications, qualifications in the fine, applied, and performing arts, and professional qualifications. General qualifications and qualifications in the fine, applied, and performing arts are awarded up to doctorate level (ISCED level 8), whereas professional qualifications are awarded up to master's level (ISCED level 7) and are predominantly associated with regulated professions. Many university programs in Sweden, particularly those relating to professional qualifications, operate on a model which is often described as the 3+2 model (cf. Swedish Higher Education Authority, 2021). In this model, students enroll in a program that is at least 5 years in duration where the first 3 years of study are at bachelor's level (ISCED level 6) and the final 2 years are at master's level. Such programs may not offer bachelor awards as they view the students as pursuing a master's-level qualification from enrolment, but may provide a letter explaining the structure of the program and that the student has the equivalent of a bachelor's degree.

The first datasets of relevance relate specifically to professional degrees, of which many are STEM related. Figure 5 illustrates the number of applications and admissions in 2020 to the most applied for professional programs in Sweden. Interestingly, the most in-demand programs were those leading to MSc qualifications in engineering fields, which sees far more male applicants than female applicants. This is followed by applications to programs leading to a BSc in nursing fields, which in contrast are applied for more by female than by male applicants.

Figure 5 The number of first-choice applicants and accepted applicants for Swedish professional degree programs with more than 1,000 qualified first-choice applicants, in the 2020 autumn semester, categorized by gender



Source: Swedish Higher Education Authority, 2021.

Of similar relevance is the data associated with graduation numbers per professional program (Table 8). The most recent data come from graduates in the 2019/20 academic year. Again, qualifications in nursing and engineering are at the top of the list; the graduation rates share a similar gender distribution to their respective application rates, and these are quite far ahead of the next nearest professional degree field.

Table 8 The 12 professional qualifications with the most graduates in the 2019/20 academic year, categorized by gender and with percentage change compared with the 2018/19 academic year

	No. of graduates		Change (%)	Gender distribution (%)	
	2018/19	2019/20		Female	Male
BSc in Nursing	4,430	4,540	+2.44%	87	13
MSc in Engineering	4,480	4,370	-2.52%	35	65
BA in Pre-School Education	2,700	2,990	+10.81%	96	4
BA/MA in Primary Education	2,320	2,780	+20.03%	80	20
MA/MSc in Secondary/ Upper-Secondary Education	2,230	2,670	+19.66%	57	43
Postgraduate Diploma in Specialist Nursing	2,250	2,630	+16.79%	87	13
BSc in Engineering	2,150	2,460	+14.46%	29	71
BSc in Social Work	2,090	2,170	+4.17%	83	17
Master of Laws	1,380	1,520	+9.54%	61	39
MSc in Medicine	1,340	1,460	+9.02%	56	44
MSc in Business and Economics	720	900	+24.31%	58	42
Postgraduate Diploma in Special Needs Training	610	870	+43.56%	93	7

Source: Swedish Higher Education Authority, 2021.

While there are many Swedish students pursuing professional degrees, it is important to contextualize this data with the data from all fields. Table 9 presents the number of students enrolled in Swedish universities in the 2019/20 academic year in all fields of study. Engineering is the STEM area with the most enrolments (90,510); however, the fields with the highest numbers of students are law and the social sciences (218,530) and the humanities and theology (103,640) respectively. Interestingly, the STEM-related areas (engineering and the natural sciences) are the only subjects with more male than female students enrolled. There is a higher percentage of female students enrolled in all other fields.

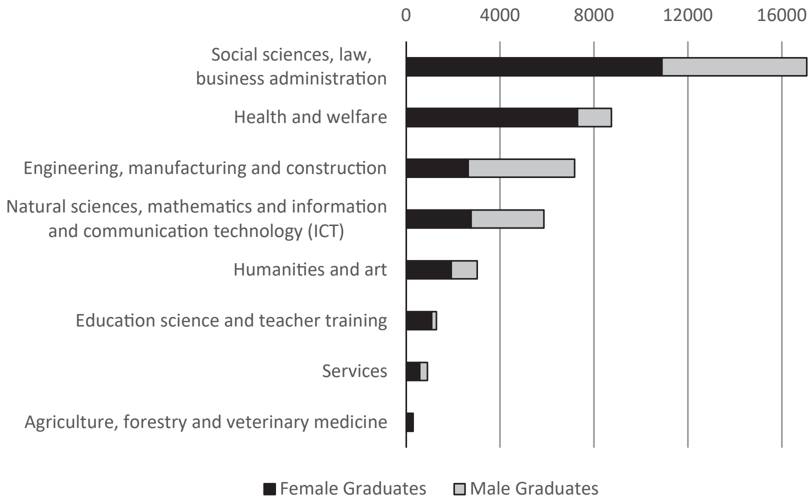
Table 9 The number of enrolled students (n = 1,182,390) in the 2019/20 academic year in total and per subject area, with percentage change compared with the 2018/19 academic year, gender distribution, and the percentage enrolled at second cycle

	No. of graduates		Change (%)	Gender distribution (%)		Percentage on second cycle		
	2018/19	2019/20		Female	Male	Total	Female	Male
Law and social sciences	210,570	218,530	+3.78%	64	36	23	23	22
Humanities and theology	95,700	103,640	+8.30%	63	37	10	10	10
Engineering	83,510	90,510	+8.38%	37	65	31	28	33
Natural sciences	74,020	82,060	+10.86%	46	54	20	21	19
Health care	39,760	40,270	+1.28%	84	16	28	29	25
Medicine and odontology	34,850	34,940	+0.26%	73	27	33	31	39
Other areas	22,740	24,770	+8.93%	60	40	21	21	21
Fine, applied, and performing arts	12,440	14,080	+13.18%	63	39	16	16	15

Source: Swedish Higher Education Authority, 2021.

Finally, a similar distribution is seen in graduation rates for students pursuing a general qualification (Figure 6). Most graduates come from the social sciences, law, and business administration, and the STEM areas of "engineering, manufacturing, and construction" and "natural sciences, mathematics, and information and communication technology (ICT)" are the only areas where a higher percentage of graduates are male than female.

Figure 6 Number of graduates (n = 44,372) with a general qualification based on the Swedish Educational Nomenclature (SUN) fields in the 2019/20 academic year



Source: Swedish Higher Education Authority, 2021.

STEM Teacher Qualifications

In Sweden, in order to be employed as a teacher you need to have a teaching certificate. A teaching certificate is issued by the Skolverket and teachers must apply for this after they graduate from a teacher education program. However, due to the current shortage of qualified teachers, this regulation has not been able to be strictly applied. In 2020, only 72% of full-time teachers were qualified with a teaching certificate (Skolverket, 2022a).

There are many ways to become qualified as a teacher in Sweden, with one commonality being that each pathway involves a placement or internship in a school to gain practical experience. Due to the structure of the Swedish education system and how until year 9 all subjects are mandatory for all students, pathways to become a STEM teacher overlap considerably with the general pathways to become a teacher. Full details on the different pathways to become qualified as a teacher in Sweden are provided by the Universitets- och Högskolerådet (The Swedish Council for Universities and University Colleges)[4]

One approach is to enroll in an undergraduate or postgraduate teacher education qualification after completing upper secondary level education. The data provided by the Swedish Higher Education Authority (Table 10) indicate that there has been an increase in graduation rates for teachers pursuing these routes since 2015/16, and that for all such programs female graduates outnumber male graduates.

Table 10 Number of graduates on teacher education programs in the 2015/16 and 2019/20 academic years with gender distribution

	2015/16			2019/20		
	Total	**Female (%)**	**Male (%)**	**Total**	**Female (%)**	**Male (%)**
BA in Pre-School Education	2350	96%	4%	2990	96%	4%
BA/MA in Primary Education	1390	86%	14%	2780	80%	20%
Extended school	360	70%	30%	690	63%	37%
Pre-school–Grade 3	660	97%	3%	1300	94%	6%
4-6	370	82%	18%	790	72%	28%
BA/MA in Education	2850	69%	31%	840	75%	25%
Higher Education Diploma in Vocational Education	470	58%	42%	480	64%	36%
MA/MSc in Secondary/ Upper-Secondary Education	920	59%	41%	2670	57%	43%
Upper-secondary schools	540	56%	44%	1810	54%	46%
7-9	390	64%	36%	860	64%	36%
Total	7980	78%	22%	9760	77%	23%

Source: Swedish Higher Education Authority, 2021.

There are a further four additional approaches to becoming qualified as a teacher in Sweden:

4 See https://www.studera.nu/ for full details.

1. If someone is already working as a teacher but does not hold a teaching certificate, they can complete further education of teachers (vidareutbildning av lärare [VAL]). If a person's experience is considered sufficient upon application, they follow an individualized plan ranging from 7.5 to 120 European Credit Transfer and Accumulation System (ECTS) credits[5].
2. If a person already holds an academic qualification in an area associated with a school subject they can complete complementary pedagogical education (kompletterande pedagogisk utbildning [KPU]). These programs range from 60 to 90 ECTS credits depending on what the person wants to and is eligible to teach.
3. If a person is qualified with a teaching degree from another country, they can supplement this to gain a qualification for teaching in Sweden through further education for foreign teachers (utländska lärares vidareutbildning [ULV]). This again is an individualized program of study of up to 120 ECTS credits which is influenced by the person's prior qualification. There is also a requirement for the person to have passed one of a selection of qualifications in Swedish to illustrate Swedish language proficiency.
4. Finally, for people who have extensive professional work experience, they can get a teacher certificate to qualify them to teach vocational subjects in upper secondary school. This is a 90 ECTS credit route.

With regards to in-service professional development, particularly given the issue of a lack of qualified teachers and as Sweden saw a decline in performance in international tests such as PISA and TIMSS in the early 2000s, a number of interventions were developed for teachers. These, in a sense, paralleled

5 1 ECTS credit equates to between 20 and 25 hours of effort. A full time academic semester typically equates to 30 ECTS credits, with a full time academic year typically equating to 60 ECTS credits. ECTS credits do not relate to the level of education, only overall hours of effort.

the previously discussed STEM-related activities aimed at students. Like the initiatives aimed at students, there are many types of in-service professional development activities aimed at teachers. Some particularly large-scale initiatives were the "boost" or "lift" initiatives which offered various courses to teachers and which had quite extensive associated research agendas to guide their implementation and observe their impact. Related to STEM, these have included Tekniklyfet (English translations: "Boost of Technology" or "Technology Lift") which ran from 2011 to 2013 (Gumaelius et al., 2019; Gumaelius & Skogh, 2015; Hartell et al., 2015; Johannesson, 2014; Norström, 2014), Matematiklyftet (English translations: "Boost of Mathematics" or "Mathematics Lift") which ran from 2012 to 2016 (Skolverket, 2018d), and Lärarlyftet (English translations: "Boost of Teachers" or "Teacher Lift") which is currently ongoing (Skolverket, 2018c). In addition, Skolverket continues to offer a significant range of in-service courses for teachers of all subjects[6]. Currently, some courses on offer for STEM subject teachers include:

- Introduction to programming in a text-based environment
- Programming activities in teaching
- Science and technology – competence development in didactics
- Mathematics – competence development in didactics
- Digital tools in science
- Sustainable development – competence development

Current STEM Education Reforms

STEM education in the Swedish pre-college education system has not seen any isolated reform in recent years. What has occurred have been curriculum-wide reforms which have included STEM education. The previous national curriculum for compulsory school was released in 2011 and the current curriculum came into effect in 2018 as previously discussed. There is a new cur-

6 For an up-to-date list, see https://www.skolverket.se/skolutveckling/kurser-och-utbildningar

riculum taking effect in Autumn 2022, but it is not yet publicly available at the time of writing this chapter. However, changes for STEM education between the 2011 and 2018 curriculum indicate a clear direction of how STEM education is being reformed.

Within the STEM subjects, the biggest changes were seen in Mathematics and Technology. These related to the introduction of programming and safety regarding the use of technology to the compulsory curriculum. The introduction of programming was predominantly seen in the Mathematics subject, with the following related core content being added:

- Years 1-3 Algebra: How unambiguous, step-by-step instructions can be constructed, described and followed as a basis for programming. The use of symbols in step-by-step instructions.
- Years 4-6 Algebra: How algorithms can be created and used in programming. Programming in visual programming environments.
- Years 7-9 Algebra: How patterns in sequences of numbers and geometric patterns can be constructed, designed and expressed in general.
- Years 7-9 Algebra: How algorithms can be created and used in programming. Programming in different programming environments.
- Years 7-9 Problem solving: How algorithms can be created, tested and improved when programming for mathematical problem-solving.

Similarly, programming has been introduced to the Technology subject but in a broader context including how programs can be used to control computers and objects. For example, the following core content was added:

- Years 1-3 Technological solutions: What computers are used for and some of the basic component parts of a computer for entering, retrieving and storing information, such as keyboards, monitors and hard disks. Some familiar objects that are controlled by computers.
- Years 1-3 Working methods for developing technological solutions: Controlling objects by means of programming.

- Years 4-6 Technological solutions: Some parts of the computer and their functions, such as processors and memory. How computers are controlled by programs and can be linked together in networks.
- Years 4-6 Working methods for developing technological solutions: Controlling pupils' own constructions or other objects by means of programming.

Further, safety with technology was also introduced as a theme in the Technology subject. This was evident through the addition of core content such as:

- Years 1-3 Technology, man, society and the environment: Addition of "and using different services via the internet to "Safety in the use of technology, such as when dealing with electricity and using different services via the internet."
- Years 4-6 Technology, man, society and the environment: Safety when using technology, for example when transferring information in digital environments.
- Years 4-6 Technology, man, society and the environment: Security when using technology, for example storing and protecting data.

A final thematic change was seen in all STEM subjects and related to the acknowledgement of the relevance of digital tools in previous core content. This was visible in the Mathematics, Technology, Biology, Chemistry, Physics, and Crafts subjects all having "both with and without digital tools" or synonymous language added to a selection of core content statements. For example, the physics core content statement of "Documentation of simple studies using tables, pictures and simple written reports" in the 2011 curriculum became "Documentation of simple studies using tables, pictures and simple written reports, both with and without digital tools" in the 2018 curriculum.

Trends and Issues in STEM Education

Many of the issues and trends associated with STEM education in Sweden have already been presented throughout this chapter. To clarify, some of the more major of these based on the authors' perspectives will be summarized in this section.

Major Trends in STEM Education

Increased emphasis on STEM in formal education

There has been a trend towards increasing the emphasis placed on STEM in compulsory education, or clarifying the way STEM instruction should be provided. One clear example is in the changes to the nationally regulated timetable. In the previous timetable, Mathematics instruction was specified at 1,125 hours for compulsory education. In the current timetable, it is specified at 1,230 hours (Table 2). An additional 105 hours was added to Mathematics instruction. The subject of Physical Education and Health also received an additional 100 hours of dedicated instruction time. These 205 hours were taken from the students choice hours, which decreased from 382 hours to 177 hours.

In addition, there has been further specification to ensure a holistic STEM education experience. The previous timetable considered Technology as a science subject along with Biology, Physics, and Chemistry. A total of 800 hours were dedicated to these four subjects. However, the Technology subject was seen as being of lower status and often was "lost" within the curriculum in favor of the natural sciences (Fahrman et al., 2015; Skolinspektionens, 2014). The new timetable, in response, has specified that 200 hours must be dedicated to the Technology subject, with the remaining 600 hours to be divided between the natural sciences as described in Table 2.

Increased responsivity to technology in society

STEM education has to constantly evolve based on societal advances. A major trend has been to respond to the increased digitalization of society in the formal curriculum. This is seen very specifically in the introduction of programming to compulsory school STEM education (Vinnervik, 2022). Children begin receiving formal education relating to programming now at the age of 6, and this continues for all their pre-college education. Similarly, in the current digital era, online and digital safety is becoming increasingly important. This has also seen a significantly increased emphasis for students primarily through the Technology subject. Given that a new curriculum is imminent so soon after the current version took effect, it is possible that it too will refine STEM education to further reflect societal needs.

Increase in STEM-related activities for students and preparation for teachers

Beyond the formal curriculum, nationally there has been a significant increase in STEM-related activities for both teachers and students. These have been previously discussed, but for students these relate to initiatives such as summer camps, museums, and informally organized learning activities such as those offered by the House of Science. For teachers, these relate both to initiatives such as the Boost of Technology or Boost of Mathematics projects organized by higher education institutions or to in-service programs offered by, for example, Skolverket. Interestingly, many of these initiatives were established in the early 2000s and their prevalence has been rising since then. This timeframe corresponds with Sweden's drop in performance in the international PISA tests, but also with international societal developments such as the increased emphasis on programming and computational thinking in schools. It is very likely that these events were instigators for the increased national STEM focus.

Female students continue to outperform male students in compulsory school STEM education

The data provided in Table 3 illustrate that female students outperformed male students in virtually all subjects in both years 6 and 9 in compulsory education in the 2020/21 academic year. As this data is openly provided for each school year by Skolverket, it is possible to see if this is a trend. For this chapter, year 9 performance only was checked as it is only year 9 performance and not year 6 performance which impacts eligibility for programs in upper secondary level and thus is considered as high stakes.

In the 2020/21 academic year, female students outperformed male students in all but the Physical Education and Health subject. This grade distribution was the same for the 2019/20, 2018/19, and 2017/18 academic years. In the 2016/17 academic year, female students outperformed male students on average in every subject, including in the Physical Education and Health subject. As such, it can be concluded that there is a trend in which female students outperform male students on average in compulsory school STEM education. This is of particular interest as there is often a narrative that males outperform female students in STEM education, but as these subjects are mandatory for all Swedish students it is particularly insightful as there are no confounding factors associated with selecting into STEM education influencing these results.

Continued national investment and prioritization of research in STEM

The Swedish government continues to invest heavily in research and research education. In 2019, SEK 19.38 billion (approximately €1.8 billion) was invested by the government to higher education institutions for research purposes (Swedish Higher Education Authority, 2021). Of this, approximately 30% was directed to the field of medicine and health sciences, 25% to the natural sciences, 16% to the social sciences, 14% to engineering and technology, 9% to the humanities and arts, and 6% to agricultural and veterinary sciences. These proportions are similar to the amounts of scholarly publications in these fields (Swedish Higher Education Authority, 2021) and to the investments made by the government in 2017 (Swedish Higher Education Authority, 2019), but since 2013 there has been a trend where funding for the natural sciences and for medicine and health science has been increasing the most (Swedish Research Council, 2021). The relevance of this to STEM education is apparent in Sweden due to initiatives like the House of Science which was set up to directly translate ongoing research activity from higher education institutions back to school students.

Major Issues in STEM Education

There is a deficit in the number of qualified teachers

By 2035, Sweden needs to graduate an estimated 153,000 students from teacher education programs related to the entire pre-college system to cover the teacher shortage (Skolverket, 2021). The need is forecast to be highest in the next five years where non-qualified practicing teachers are expected to be replaced by those with qualifications or to gain qualifications themselves. Specifically, the shortage of new graduates is predicted to be greatest among vocational teachers and subject teachers with a focus on students in years 7-9. If current graduation rates continue, in 2035 Sweden is forecast to still be short of approximately 12,000 qualified teachers.

Much of this teacher qualification shortage relates to STEM areas, which is particularly problematic as there are no fixed numbers of students that can be in a classroom at a given time and there is no set number of hours a teacher can teach. These decisions are made locally by school principals based on the school budget. If principals have a teacher shortage, they can make decisions such as to increase the number of students in a classroom, which can have a negative impact on student learning.

Further to this, in July 2015 a regulation was introduced to restrict authority to award grades to compulsory school students to only certified teachers. However, due to the teacher supply shortage, non-certified teachers are still allowed to teach and assess their students. However, to accommodate the regulation, a certified teacher must supervise the assessments made by uncertified teachers. This regulation change is particularly problematic for the mandatory subject of Technology where the shortage of subject-specific qualified teachers is greater than for most other mandatory school subjects. Consequently, principals will encounter difficulties in following the regulations, and qualified teachers have additional requirements.

There are on-going initiatives to resolve this issue. Two issues are described by Axelsson (2019) as:

- A new career reform program for teachers was introduced in 2013, offering a substantial increase in salary for appointed qualified teachers, paid for by the government, and
- There has been an increase in funding for teacher education to higher education institutions since 2015 to establish more student places on these programs.

Females are underrepresented in STEM fields at upper secondary and higher education

A phenomenon that is quite common in Western societies is that females are underrepresented in STEM fields. In Sweden, this cannot be seen at compulsory school level as students do not make choices regarding the subjects they study at this stage of their learning. This type of choice first becomes available at upper secondary level. This characteristic of the Swedish education system makes examining gender differences in subject choice particularly interesting, and the relevant data are openly provided by Skolverket (2022c).

For this chapter the data of program applications at upper secondary level for the previous 5 years was examined (Table 11). This reveals that, despite a shared written curriculum and better performance on average across all subjects including the STEM areas, females are notably more likely to apply to the programs of Health and Social Care, Social Science, Handicraft, Children and Recreation, and Natural Resource Use than males, who are notably more likely to apply to the programs of Electricity and Energy, Technology, Building and Construction, and Vehicle and Transport. It is at this stage in Sweden that gender differences in fields of study become apparent. This difference then continues to post-secondary education as previously discussed where female students apply at greater rates to, and are more represented in, third level programs associated with nursing, education, law, the social sciences, and the humanities, while male students apply more to and are more represented in engineering programs (Figure 5, Figure 6, Table 8, Table 9).

Responding to the gender differences in STEM is a significant endeavor in Sweden. At a national level, general equality is a governmental priority which is visible through their gender equality policy. This policy includes six subgoals which are not mutually exclusive, but of which one is that women and men must have the same opportunities and conditions with regards to education, study options, and personal development. At more local levels, gender equality in education is a priority of much social science research and is conducted from multiple perspectives. Also, there are a myriad of initiatives to support and promote women in STEM, such as the Tekla festival which is a free technology festival for girls and non-binary people aged 11-15.

Table 11 Percentages of female and male applicants to Swedish upper secondary level programs, organized by the average percentage difference across each of the last five years

Program	2021/22		2020/21		2019/20		2018/19		2017/18		Average difference
	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	
Health and Social Care	20.6	2.9	19.2	2.9	20.1	3.9	21.0	6.0	21.4	4.7	16.4
Social Science*	35.7	20.4	35.4	19.9	34.8	21.0	33.9	20.0	33.2	19.7	14.4
Handicraft	12.9	0.8	14.1	0.8	14.5	1.0	15.6	0.8	16.3	0.8	13.9
Children and Recreation	15.9	5.9	17.4	6.3	17.8	6.8	16.8	6.5	15.4	6.5	10.3
Natural Resource Use	16.1	5.0	14.2	4.4	13.4	4.3	13.2	3.9	13.3	4.0	9.8
Arts*	11.7	7.0	11.3	7.6	12.2	7.6	12.1	7.5	12.5	7.3	4.5
Business and Administration	10.7	7.0	11.3	7.1	12.1	7.1	11.0	6.6	11.7	6.8	4.4
Hotel and Tourism	2.7	0.6	3.4	0.7	4.4	1.0	4.8	1.0	4.9	1.1	3.1
Natural Science*	21.5	19.2	22.6	19.5	22.7	20.3	23.2	21.0	24.5	22.2	2.5
Restaurant Management and Food	4.7	3.3	4.4	3.3	5.0	3.4	5.3	3.4	6.0	3.6	1.7
Humanities*	1.2	0.3	1.2	0.4	1.4	0.3	1.5	0.4	1.6	0.4	1.0
Business Management and Economics*	23.5	27.0	22.8	26.4	22.3	24.4	22.4	23.5	21.6	22.8	-2.3
Industrial Technology	0.8	5.2	1.2	5.6	1.0	6.0	1.2	6.0	1.2	6.0	-4.7
HVAC (heating, ventilation, and air conditioning) and Property Maintenance	0.4	5.3	0.3	5.5	0.3	5.6	0.3	5.0	0.3	5.6	-5.1
Vehicle and Transport	8.7	19.6	7.8	19.6	6.1	18.9	5.5	18.1	4.7	17.0	-12.1
Building and Construction	4.3	19.7	4.4	19.7	3.4	18.5	3.6	19.5	3.2	20.7	-15.8
Technology*	4.9	24.8	5.2	25.0	5.1	25.1	5.3	26.3	4.9	26.2	-20.4
Electricity and Energy	1.5	23.3	1.5	22.8	1.3	22.2	1.4	21.9	1.3	21.8	-21.0

Note: Programs marked with an asterisk (*) are from the higher education preparatory strand. Programs without an asterisk are from the vocational strand. Percentages are within strand percentages. For example, in the 2021/22 academic year, 20.6% of only the female students who applied to a vocational program as a first choice applied to the Health and Social Care program. Similarly, in the 2021/22 academic year, 35.7% of only the female students who applied to a higher education preparatory program as a first choice applied to the Social Science program.

Lack of dedicated time for STEM education subjects

Despite the STEM subjects being mandatory for all students and also having a dedicated amount of minimum teaching hours allocated to them, there have been reports suggesting that students are not experiencing enough in these subjects to have the chance to meet the defined learning outcomes. This situation has gained particular attention in the early years of school in science education (Skolinspektionens, 2012) and in the Technology subject (Hartell, 2015).

With regards to this issue, it is important to note that each teacher is free to design their own pedagogical approach and to autonomously structure the organization of student learning, provided they work within the national curriculum and minimum hours of instruction. The issue arose previously as a result of 800 hours of instruction being allocated in total for Biology, Physics, Chemistry, and Technology. Teachers and schools could "lose" some subjects, particularly Technology, within the 800 hours and over-emphasize others. An approach that was recently implemented was to add further specificity to the 800 hours. Now students have 200 hours of dedicated Technology education, and 600 hours of science education with at least 130 hours to be provided in each of the three natural science subjects.

Ambiguity in the technology subject

In addition to the issues associated with the teacher shortage in general and a lack of time for STEM education, the Technology subject has some independent issues. A primary issue is that as a subject it is not fully understood. This is a challenge internationally with technology education (de Vries, 2016). In Sweden, much of this issue stems from Technology previously being incorporated within science education which gave it an implicit context it no longer has. In fact, Technology is the new compulsory subject in the Swedish compulsory school curriculum. It is also the only explicit STEM subject without a national test.

Some of the problems related to the subject were mitigated through clarifications in the national curriculum. However, the problem persists. Few teachers received education in the curriculum, and textbooks and tests for national assessment were unavailable. As a result, there is reason to believe that the subject of Technology varies more between schools than other subjects in terms of content, complexity, pedagogy, and assessment.

Multiple approaches are being taken to rectify this issue. For example, there are now more formal routes to qualify as a Technology teacher and government mandates for teachers to receive such qualification. There continues to be in-service education for Technology teachers. However, despite efforts there is still a need to do more to establish Technology as an independent and cohesive subject.

Lack of teacher preparedness to teach Technology

A final issue pertaining to STEM education relates to practicing teachers' preparedness to teach the Technology subject. As discussed, there are issues concerning access to resources; however, this issue also relates to low levels of Technology teachers' self-efficacy. A number of studies such as the work of Hartell et al. (2015) have identified that Technology teachers have low self-efficacy to teach and assess students within the subject. The impact of this is that the Skolverket concluded that parts of the curriculum are not being taught as teachers avoid those areas which they are less confident in engaging with. The work of Hartell (Hartell, 2015; Hartell et al., 2015) has led to a number of conclusions in this regard, including that:

- Teachers who are trained in the subject expressed greater self-efficacy in assessing their students.
- Trained teachers emphasize a significantly greater use of curricula in technology as the basis of their teaching.

- Subject-specific trained teachers expressed greater self-efficacy in describing what is expected of their students.

The general solution to this issue, as with the previous issues, appears to be a need for more teachers to become qualified to teach the subject, as engagement with formal education through one of the many available routes increases preparedness to teach.

Conclusion

The purpose of this chapter was to illuminate where STEM education features within the Swedish pre-college education system. The Swedish system is quite interesting in this regard as at least up until year 9 all students in mainstream education receive the same national curriculum. Therefore, until this time there are no decisions to be made in terms of participating formally in STEM education or not. Students can make this choice for upper secondary level education, and this choice relates to a program type (e.g., a vocational program or higher education preparatory program), a specific program of study, and then a specialization within that program. These choices have a significant impact on the post-secondary direction a student can and likely will follow based on current associative data.

The education system has seen a number of trends as it relates to STEM education. For example, there has been an increase in mathematics instruction and increased clarification around science and technology instruction. Within compulsory STEM education, a consistent trend has been that female students outperform male students. STEM education has also evolved to emphasize digitalization more in terms of programming and digital safety. Also, national investment in research activity associated with STEM is seeing a rising trend, and there are national initiatives to translate this knowledge back into precollege education. That said, the Swedish education system is not without its issues. Most issues stem from a significant lack of formally qualified teachers, but there is also an issue of low female representation in STEM from upper secondary education onwards, and specifically in the Technology subject there is a need to work towards making the subject more epistemologically cohesive.

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Status and Trends of STEM Education in Taiwan

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Abstract

Rising attention has been focused on STEM education for a decade for the purpose of cultivating STEM talent to fulfill the shortage of professionals. In Taiwan, STEM education was first designed as an integrated course in the last version of the curriculum guidelines, which combined technology education with science education into one domain. Nowadays, STEM education has been pointed out as a crucial component in the newly released 12-year curriculum guidelines, and is generally implemented as an alternative course in formal education as well as in non-formal education such as school clubs, camps, competitions, and so on. This chapter aims to present detailed information, including the history, contexts, goals, and activities designed for both formal and non-formal education, learning assessment, and teacher education for pre- and in-service teachers, regarding STEM education development in 12-year compulsory education (including elementary and secondary schools) as a brief introduction to STEM education status in Taiwan. As STEM education has become a popular theme at every education level, several ideas of trends are summarized to present the changes and the latest news on STEM education development. In addition, some issues are also proposed such as challenges that teachers encounter in STEM teaching or gaps between policy and practices that need to be discussed to highlight the important topics and problems of STEM education in Taiwan.

Keywords: Taiwan, curriculum, teacher education, STEM education, technology education

Introduction

With the trend of technology development, industrial transformation has led to growing demand for people to enter Science, Technology, Engineering, and Mathematics (STEM) related occupations. According to a report of the National Development Council (2021), the proportion of STEM talent shortage reached 63.5% (about 25,000 people) of the total needed in 2020, mainly including the information technology, science, statistics, and engineering fields. Furthermore, the number of students majoring in STEM fields has declined from 35.4% to 31.8% over the past decade. Reports have shown several reasons for the abovementioned talent shortage challenges, for example, the low birth rate and the flow of STEM talent. Therefore, the government has expressed eagerness to increase the number of STEM professionals and enhance Taiwan's international competitiveness through education.

The 6-3-3-4 education system in Taiwan represents the 12-year basic education of Taiwan's schooling structure, starting with the 6-year elementary school stage, the 3-year middle school stage, followed by the 3-year upper secondary school stage (including general and technical high schools). After finishing compulsory education (Grades 1 to 12), college or university education is where students can pursue higher education, and it generally takes another 4 years to graduate with a bachelor's degree (see Table 1 for Taiwan's schooling structure). STEM in compulsory education is strongly related to technology education. The technology domain, which consists of Living technology and Information technology courses, was newly added in the latest curriculum guidelines for the purpose of emphasizing technology education and STEM education in the 12-year basic education. As for higher education, the Ministry of Education (MOE) has announced three policies: expanding enrollment by 10-15% in STEM-related departments, diminishing the restriction on the teacher-student ratio in STEM departments, and encouraging the offering of interdisciplinary programs to increase the student proportion in STEM-related departments. Apart from formal education, support is also given for informal STEM activities; for example, STEM camps and STEM competitions allow students to explore and gain interest in STEM careers. The following section provides the details to better present the status and trends of STEM education in Taiwan.

Table 1 Taiwan's schooling system structure

Education stage	Grade
Elementary school	Grade 1
	Grade 2
	Grade 3
	Grade 4
	Grade 5
	Grade 6
Middle school	Grade 7
	Grade 8
	Grade 9
Upper secondary school	Grade 10
	Grade 11
	Grade 12
College/University	Freshman
	Sophomore
	Junior
	Senior

The Status of STEM Education

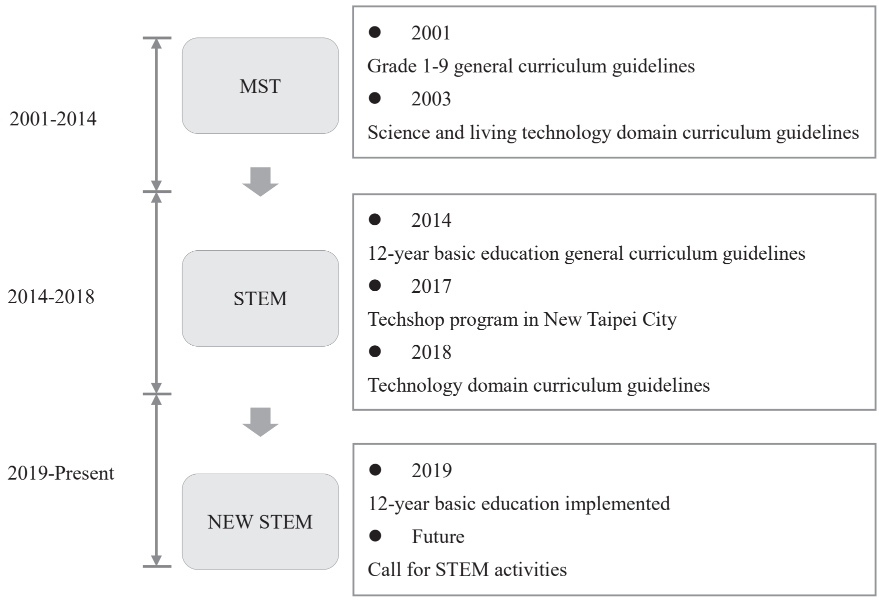
Contexts of STEM Education

According to the 2021 IMD World Digital Competitiveness Ranking reports, Taiwan ranked seventh in the level of country preparedness to exploit digital transformation, and ranked fifth among graduates in sciences (including Information and Communication Technology, Engineering, Mathematics and Statistics, Natural Sciences, and Manufacturing and Construction). Nonetheless, the MOE's 2020 survey found a decline in the student ratio in STEM fields, with the percentage of students in STEM-related departments gradually declining from 35.4% to 31.8% between 2011 and 2020 (National Development Council, 2021). Considering this trend, cultivating the next generation's STEM talent is a challenge for Taiwan's STEM education. The government has emphasized STEM education at all education levels; however, the present article mainly targets the status of STEM education for K-12 students.

The development history of STEM education for compulsory education in Taiwan can be traced back to the Grade 1-9 Curriculum Guidelines released in 2001 (See Figure 1). Science and technology subjects were combined into one domain to promote integrated Mathematics, Science, and Technology (MST) education. The latest curriculum guidelines for the 12-year basic education and technology domain were released in 2014 and 2018, respectively, and were implemented in 2019. Few STEM education details have been mentioned or included in either the general curriculum guidelines or the subject-specific curriculum guidelines for the 12-year basic education. Although the technology domain curriculum guidelines address the concept of engineering design and interdisciplinary STEM education at the upper secondary school stage (Ku & Lin, 2020), the main ideas of the guidelines still focus on technology education instead of STEM education. To sum up, there has been a lack of systematic organization for STEM education in 12-year basic education.

In addition to the curriculum guidelines, the local education bureaus have their policies regarding STEM education. The Techshop program, for example, is the first STEM education policy which ran by a local education bureau. The Techshop program aims to encourage secondary schools in New Taipei City to create STEM-based lesson plans that conform to schools' characteristics and orientation. A STEAM consulting group based in New Taipei City consists of 23 members, offering STEAM lesson plan modules and training courses for teachers who are interested in conducting STEM/STEAM education. Although the policy for STEM education still needs to be formally discussed and formulated, it can be seen that interdisciplinary education has been emphasized in 12-year basic education from multiple perspectives.

Figure 1 STEM education in Taiwan



Source: Lin, 2018.

STEM Education Goals/System/Framework

Analyzing the goals of STEM education has been a popular research topic since experts and researchers have yet to reach a consensus on the issue. Lin et al. (2022) summarized different research results and national documents regarding STEM education goals, and surveyed secondary school STEM teachers to explore their perceptions of STEM education goals in Taiwan. The findings revealed three categories of STEM education goals, namely cultivating students' 21st-century skills, STEM literacy, and capabilities of interdisciplinary problem-solving. The skills of lifelong learning, leadership, critical thinking, collaboration, and so on, were regarded as critical 21st-century skills that students need to cultivate through STEM education. STEM literacy was defined as literacies of the four disciplines: scientific, technological, engineering, and mathematical. Capabilities in interdisciplinary problem-solving refer to applying higher-order abilities to solve interdisciplinary problems; for instance, students should be able to deconstruct various situations and define the problem before starting to generate solutions. With the research findings, education policy makers could have an explicit picture of STEM education goals and frame policy for STEM education.

STEM-related Activities

Researchers have identified the benefits of STEM education for Taiwan's students either in formal education (Lin et al., 2020; Lin et al., 2021) or in non-formal education (Ku et al., 2022). Even though STEM education policy details are lacking in curriculum documents, efforts have been made by school teachers, institutions, and organizations to promote students' interest in learning STEM and to enhance their intention to pursue STEM professions. The following provides several examples of STEM-related activities in formal and non-formal education.

Formal Education

The curriculum types of the 12-year basic curriculum are classified into the MOE-mandated curriculum and a school-developed curriculum. The former was planned by the government and the latter was designed by an individual school to highlight the features, which means schools can offer courses they consider beneficial for students' development. Since details for planning and developing STEM education are not included in the curriculum documents, STEM-related activities, in general, take place in school-developed curricula (in the "Alternative curriculum" for primary and middle schools, and in the "Alternative learning period" for upper secondary schools). Teachers have been aware of the importance of STEM education for some time; however, they know little about how to create a STEM-related activity because they have not received relevant training. As a result, the Maker and Technology Centers, founded to assist technology education in the 12-year basic education, are responsible for developing STEM-related modules, offering them to teachers who are willing to implement STEM education in a school-developed curriculum. Besides, several STEM activities were developed based on schools' orientation under the Ministry of Science and Technology's (MOST) encouragement; for example, the "Mushroom experiment" and "Incubators design" are science-based STEM activities; "Mousetrap car," "Bridge design," and "Seismic structure design" are technology-based; the "Robotics project" and "Quadcopter project" are engineering-based; and "IQ light" is a project based on Mathematics. A brief description of the "Earthquake Engineering Building Design" activity is given below as an example to present a STEM-related activity in Taiwan's formal education.

The Earthquake Engineering Building Design project is a well-known STEM-related activity that can be designed for students at any level. Since earthquakes can cause considerable damage and are a serious issue in many countries, it is regarded as a real-life context that can allow students to apply different types of knowledge and abilities while solving problems. Massive earthquakes that struck off the central part of Taiwan in 1999 and Hualien in 2018 both caused tremendous damage, such as schools and houses collapsing; earthquake-resistant building design has thus received attention and discussion for many years. The mission is to design an earthquake-resistant building model that can withstand earthquake forces under certain limitations. Limitations can be locations in which the building would be constructed, the height of buildings, the size of foundations, budget constraints, materials, appearance, and so on. At the end of the project, a shake test takes place to assess the seismic strength of models until the model collapses (see Figures 2, 3, & 4).

A lesson plan of the Earthquake Engineering Building Design project designed for upper secondary school students, as an example, requires students to work as a team to design and construct an earthquake-resistant building model, following the engineering design process. The limitations include: the model must be built with three stories; the total model height needs to be no lower than 35 cm; and the structure materials are fixed and are provided by teachers to ensure equality. Apart from the abovementioned conditions, each team is asked to provide a portfolio that involves design drawings, structural data analysis results, and records of their design process. At the very beginning of the project, students need to learn about the engineering design process and acknowledge how an engineer solves the problem with the process instead of trial and error. Following, in order to design a well-structured model which is earthquake-proof, students need to analyze the structure design problems of those collapsing buildings and identify the crucial ideas that may affect seismic strength. Searching for information online, observing structure design in real-life, design drawing and modeling with software, or making simple artifacts may help students create and test their ideas on constructing an earthquake-resistant building. Finally, students need to use the technology tools to build their models appropriately. During the whole design and making process, students apply critical 21st-century skills and capabilities in interdisciplinary problem-solving while cultivating their STEM literacy. To summarize, the Earthquake Engineering Building Design project is a STEM-related activity with which teachers can effectively achieve the STEM education goals in formal education.

Figure 2 Building model

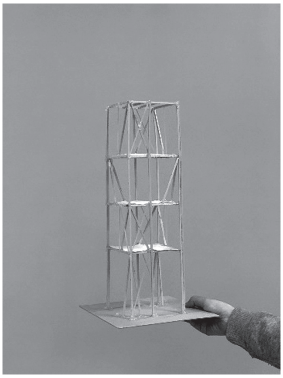


Figure 3 Shake test

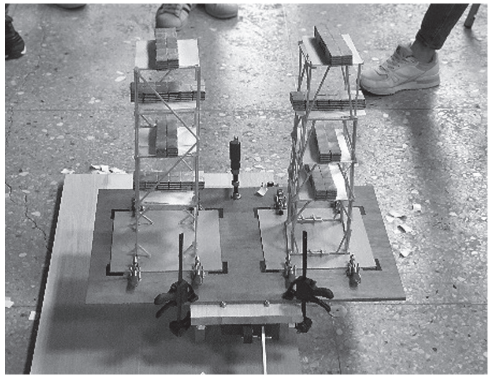
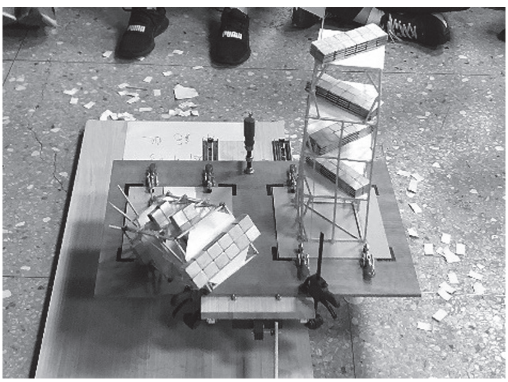


Figure 4 Collapsing model



Non-formal Education

In addition to formal education, non-formal education has also been identified as being beneficial for enhancing students' attitudes, emotions, values, and beliefs about learning (Greenhill, 2007). Studies further support that participating in STEM-related camps or competitions helps engage their STEM learning attitudes and motivation (Ku et al., 2022; Roberts et al., 2018). Due to the rising importance of disciplinary abilities, not only schools but also parents and communities have focused great attention on STEM education and want to cultivate the younger generation's STEM literacy. Recently, an increasing number of STEM-related activities, such as school clubs, camps, and competitions, have been provided by various organizations, including the government, educational institutions or associations, private cram schools, and so on. The following introduces STEM-related camps and competitions held by the government or traditional educational institutions to demonstrate STEM education development in non-formal education.

"Maker camps" were winter camps organized by the Department of Education Taipei City Government during winter vacations, designed for students in elementary schools and middle schools (Edtech Taiwan, 2020). The Maker camps were organized and held by six Maker and Technology Centers in Taipei City, providing 49 series of STEM-related activities involving 1,000 applicants (272 of whom were elementary school students, while the remainder were from middle schools). The camps included rich learning content of STEM-related hands-on activities such as automatic sprinkler systems used in gardens, controlling cars using electronic components, robotics with a micro:bit, and so on. The aim of Maker camps is to cultivate students' STEM literacy through different activities in order to meet their future needs and prepare them for professions.

STEM competitions are another effective way to challenge students' existing knowledge and to facilitate their learning of unfamiliar STEM knowledge and abilities. There are numerous STEM competitions with different themes and contexts in Taiwan. The Annual National Technology Competition targets middle school students (Grades 7-9) and is held by the government (Ku et al., 2022; National Technology Contest, 2021). During the competition, students need to apply their knowledge and skills to complete the missions without teachers' assistance. The themes change every year and the arranged missions are slightly different for each region; for example, the conditions of venues may vary from one region to another. This year, the theme was goods delivery, which has been a popular topic since the pandemic began. In this case, students worked as a group consisting of no more than three members to design the specified devices: electronic control cars with hydraulic arms as well as batting devices using the hydraulic principles (see Figures 5 & 6). Students who participated in the competition were required to control the car to carry and deliver goods of different shapes to the designated platforms (including lifting goods onto the platforms) and then launch goods to the targeted areas. That is, students needed to utilize STEM-related knowledge and abilities and higher-order skills such as creativity and collaboration skills to solve encountered problems while designing and creating the devices.

Besides the competition mentioned above, GoSTEAM is a STEM-related competition held annually, requiring upper secondary school students to design a ball screw mechanism with multiple types of structures and mechanisms (see Figure 7) (MOE, 2021). The Start! AI Car competition is another STEM-related competition held for elementary and middle school students. The goals of the competition are to support students in learning artificial intelligent applications and applying STEM-related knowledge and skills to solve problems. The theme for 2022 was sensors of image identification that can be installed on robots to carry out emerging rescue missions (Start! AI Car x Ardublockly, 2022). The robots need to be designed as programming control with an obstacle avoidance system using image identification sensors to complete the missions (see Figure 8).

Figure 5

Control car designed by participants

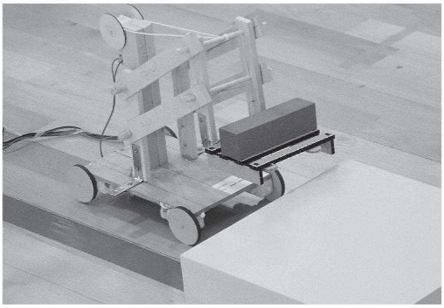


Figure 6

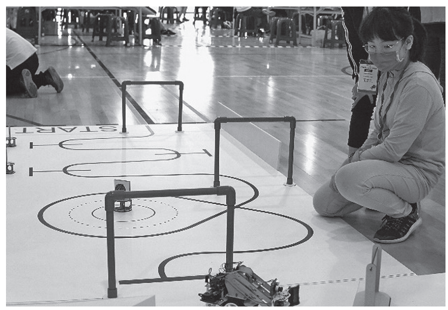
Competition venue in 2021

Figure 7

GoSTEAM competition 2021

Figure 8

Start! AI Car competition 2022



Moreover, STEM-related aids developed by publishers are easy to use for young children to experience STEM activities. A robotics aid called Geckobot, for example, is a wall walking robot created with Gigo which allows users to learn physical phenomena, bionic-like motions, mechanical applications, simple programming, and so on, with their creativity (Gigo, n.d.). Exhibitions in museums also offer non-formal learning experiences for students to understand STEM-related knowledge and applications. For instance, the National Science and Technology Museum holds multiple theme exhibitions regarding technology artifacts, such as “Locks and Keys” (National Science and Technology Museum, n.d.), in which students learn about the evolution of technology as well as the relationship between humans, society, and technology. The non-formal STEM-related activities enable students to enrich experiences of learning STEM in diverse ways and help prepare the next generation's interest in pursuing STEM-related careers.

STEM Learning Assessment and Career Development

The Programme for International Student Assessment (PISA) examines students' reading, science, and mathematics literacy every 3 years to see whether they are able to apply crucial abilities to social engagement. The Organisation for Economic Co-operation and Development (OECD) released the latest results of PISA in 2018 (OECD, 2018). The findings indicated that students' reading performance in Taiwan ranked 17th out of 79 countries, slightly improved from the results of 2015; science performance ranked 10th, and mathematics performance ranked fifth. Apart from the ranking, several issues were also described: (1) underachieving students did not show significant improvement in performance; (2) Taiwan's students reached a high ranking on the index of fear of failure; and (3) students were not familiar with computerized adaptive testing (CAT).

The Trends in International Mathematics and Science Study (TIMSS) is hosted by the International Association for the Evaluation of Educational Achievement (IEA) every 4 years for the purpose of tracking students' mathematics and science achievement trends and understanding the influences of curriculum, teaching, and learning environment, teachers, capital backgrounds, and so on. Not only achievement assessments but questionnaires on students' attitudes toward learning mathematics and science are also included in TIMSS. The results of TIMSS 2019 (TIMSS Taiwan, 2019) revealed that fourth-grade students' mathematics and science performances ranked fourth and fifth out of 58 countries, respectively; eighth-grade students' mathematics and science performances both ranked second out of 39 countries. Even though students performed well on cognitive assessments, they showed low interest and confidence and placed low value on learning mathematics and science. The possible reason for this situation could be the over-emphasis on cognitive learning. Teaching and learning in Taiwan generally have a strong connection with examinations, which causes a lack of opportunities for students to explore their interests.

To conclude the abovementioned information on students' performance related to STEM education, the following ideas were generated: the literacy of social engagement needs to be improved; different types of tests should be planned for students such as examinations with computers; more opportunities must be provided for students to increase their confidence in experiencing failures and to explore their interests in science, technology, engineering, and mathematics-related fields. Nonetheless, an increasing number of changes have been made over a decade, including emphasizing literacy instead of cognitive learning in K-12 education and enhancing students' literacy and interest in STEM through various kinds of formal and non-formal education; a world-wide assessment system for the measurement of students' STEM performance has yet to be developed.

Many concerns have been raised regarding the assessment or evaluation of STEM education. Although several studies have contributed to assessing students' performance in STEM learning, most of them have tended to focus on knowledge and affection in separate disciplines, or transdisciplinary affection (Gao et al., 2020). The STEM research team at National Taiwan Normal University (NTNU) has been working on a context-based STEM competency online assessment to assess students' performance in interdisciplinary problem-solving competency. STEM education emphasizes authentic contexts (Kelley & Knowles, 2016), which means that the contexts need to be related to students' life experiences and provide them with opportunities to utilize interdisciplinary competency to solve real-world problems (Ku et al., 2022). Accordingingly, contexts for online assessment are designed with real-life situations and highlight students' STEM competencies such as contextualization, predictive evaluation, analogical reasoning, quantitative thinking, and reflective ability (Lin et al., 2022a).

The three contexts were designed considering engineering contexts by Science, Technology, and Mathematics teachers in secondary schools. The first context is proposing an alternative strategy to solve traffic congestion on Freeway No. 5, which has been a severe problem, especially on holidays; the second context is constructing a reservoir for the Jin-Sih area, which faces the challenge of water conservation issues due to the growth in both population and industry; and the third context refers to reconstruction of a bridge that collapsed in 2019 in Yilan county to reconnect the transportation between ports (see Figure 9 for the contexts). In the context-based STEM competency online assessment, students are given information of multiple types such as text, videos, figures, news, and data presented in tables; furthermore, using modeling software to investigate the data and their hypotheses is also needed. Therefore, it is necessary for students to utilize the STEM competencies to answer multiple-choice questions and matching questions based on given information when taking the assessment. A radar chart and score results presenting students' performance on STEM competencies are shown after the assessment is completed (see Figure 10 & 11).

In order to show the value of STEM education, the assessment mainly focuses on helping teachers to understand students' performance on competencies that can hardly be cultivated in separate disciplinary learning. The five STEM competencies were taken from Lin et al.'s (2022a) study results, revealing the interdisciplinary problem-solving capabilities that students should improve after taking STEM education. The results of the context-based STEM competency online assessment allow teachers to adjust their teaching arrangement and lesson plans as well as enabling students to reflect on their learning processes. Although the efficiency of the designed assessment is still under research, it shows a different aspect of assessing students' STEM learning performance from the existing STEM assessment and evaluation instruments, and may contribute to STEM learning evaluation.

Figure 9 Three contexts in the context-based STEM competency online assessment

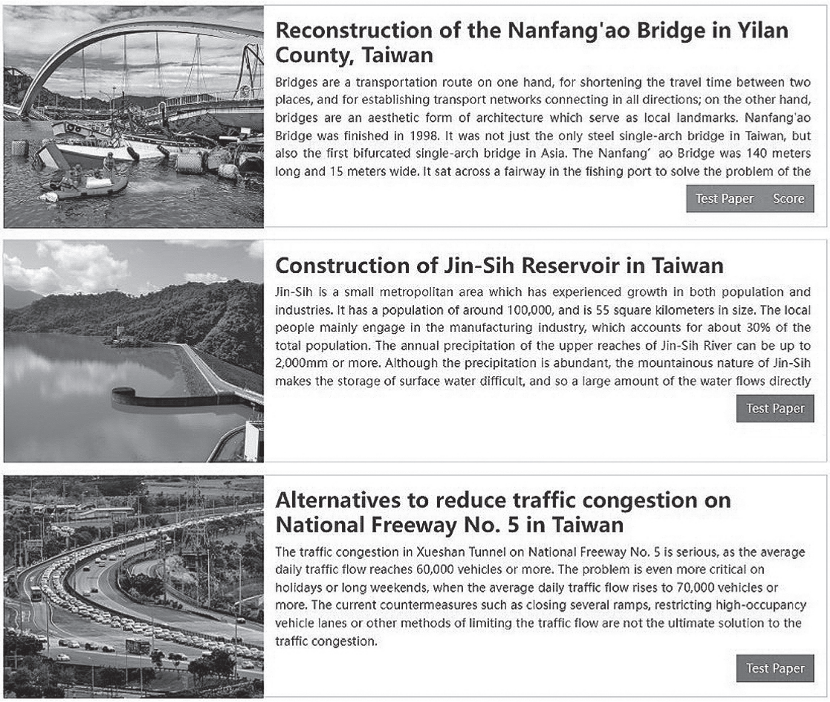


Figure 10 Rader chart results of the context-based STEM competency online assessment

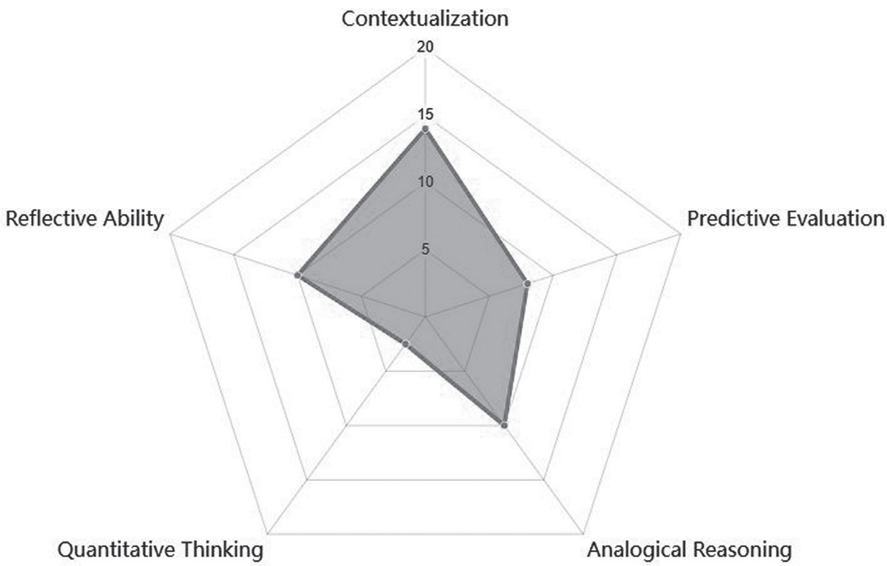


Figure 11 Score results of the context-based STEM competency online assessment

Competency Indicators	Your Marks	Total sub-category marks
Contextualization	14.00	20
Predictive Evaluation	8.00	20
Analogical Reasoning	10.00	20
Quantitative Thinking	2.50	20
Reflective Ability	10.00	20
Total marks	44.50	100

STEM Teacher Education and Professional Development

The increasing attention to STEM education has led to the need to fill the shortage of qualified STEM teachers; therefore, higher educational institutions or teacher educators have been working on developing STEM teacher education programs for many years. Researchers (Lin & Williams, 2016; Yu et al., 2021) have indicated that teachers show firm teaching intention if they acknowledge the value and have enough ability to implement the curriculum. Further research conducted by Kucuk and Sisman (2017) as well as Yang et al. (2020) stated that teachers' teaching ability might influence robotics education which is widely employed in STEM activities. As far as we are aware, most teacher education programs in Taiwan focus on single disciplines instead of offering interdisciplinary training courses; thus, teachers feel less confident in interdisciplinary education such as STEM activities. Accordingly, it is imperative to organize STEM teacher training courses for both pre- and in-service teachers for the purpose of enhancing their perceptions of STEM education value and teaching ability.

Mak et al. (2022) collected STEM teacher education programs that presented detailed information in English and Mandarin from worldwide universities, and they summarized three different categories by the length: degree programs, certificate/diploma programs, and short-term training programs. Degree programs refer to the most prolonged training courses, which may last for years, and students who complete the programs receive a degree as a STEM teacher, while certificate/diploma programs usually require students to take no less than four STEM-related courses, and thus can be completed in a few months to a year. Although there exist differences between course arrangements in degree and certificate/diploma programs, they both put effort into drawing a comprehensive map of STEM education for students. In addition to degree and certificate/diploma programs, short-term training programs are generally held on weekends or holidays, which means the duration is shorter than the abovementioned two programs. The primary purpose of short-term training programs targets training in-service teachers' practical teaching knowledge and ability, for instance, collaboration skills, STEM-related lesson planning, or resource acquisition and operation.

The following briefly introduces the existing STEM teacher education preparations in Taiwan according to the categories described above. To the best of our knowledge, there is a master's degree related to cultivating STEM teachers; two certificate programs target pre- and in-service teachers, respectively; various short-term training programs for in-service teachers' professional development are provided by public or private organizations (two examples are presented in the current article) (see Table 2 for information). For degree programs, National Taiwan Normal University offers a Ph.D. degree in integrative STEM education, targeting international students with interest in becoming future STEM innovative educators, leaders, scholars, and researchers. The Ph.D. program requires 18 credits to graduate, including 12 credits in program courses and 6 credits in selective courses. National Tsing Hua University offers a master's degree in interdisciplinary STEAM Education, targeting in-service teachers with at least 2 years of teaching experience. The master's degree program requires 27 credits to graduate, including 12 credits in mandatory courses and 15 in elective courses. All the courses are categorized into three themes: Research methods, Research on theory and issues of interdisciplinary STEAM, and Practices of interdisciplinary STEAM education (Table 3). "Research methods" include qualitative and quantitative research method courses; students can take either of them. "Research on theory and issues of interdisciplinary STEAM" includes two mandatory courses and five elective courses the content of which is mainly related to STEAM teaching and learning, evaluation, and issues exploration; while "Practices on interdisciplinary STEAM education" involves six courses (one is mandatory, and the remainder are elective), emphasizing practical STEAM teaching ability.

Table 2 List of STEM teacher education programs in Taiwan

Program	Institution/Organization
Degree programs	
Ph.D. degree in integrative STEM Education	National Taiwan Normal University
Master's degree in interdisciplinary STEAM Education	National Tsing Hua University
Certificate/diploma programs	
Pre-service STEAM teacher certificate program	Tsinghua STEAM School
In-service STEAM teacher certificate program	Tsinghua STEAM School
Short-term training programs	
Training courses and workshops	NTPC STEAM
Workshops	Maker and Technology Centers

Table 3 Course arrangements of master's degree in interdisciplinary STEAM education

Themes	Courses
Research methods (pick one of two)	Qualitative research methods (mandatory)
	Quantitative research methods (mandatory)
Research on theory and issues of interdisciplinary STEAM	Research on STEAM theory (mandatory)
	Research on the nature of STEAM education (mandatory)
	Research on STEAM curriculum and evaluation
	Research on design thinking
	Research on technology and arts application
	Research on global issues of STEAM education
	Research on STEAM teaching environment
Practices of interdisciplinary STEAM education	Research on STEAM activities development (mandatory)
	Research on STEAM-based problem solving
	International cooperation on STEAM education
	Research on early childhood STEAM education
	Research on non-formal STEAM education
	STEAM education research practice

Source: National Tsing Hua University, 2021.

Apart from that, Tsinghua STEAM School has developed certificate programs for pre- and in-service teachers who have the intention to implement interdisciplinary education. Tsinghua STEAM School, funded by the MOE, aims to improve pre- and in-service teachers' STEAM teaching ability through systematic teacher training programs. For pre-service teachers, either theme-A or theme-B must be completed as well as the two mandatory courses (Table 4). Theme-A consists of (a) a STEAM education specified course referring to experiencing STEAM education and solving problems through STEAM competency; (b) a STEAM teaching method course referring to designing and developing STEAM activities; and (c) a STEAM practicum course relating to teaching strategies and practices in STEAM education which cultivate similar ability to the course of STEAM camps in elementary and secondary schools planned in theme-B. In comparison, courses in Theme-B are more about practical experiences: (a) STEAM workshops including 12 hours for introductory workshops and 18 hours for advanced workshops; (b) STEAM online micro-courses require students to take 6 hours of online courses regarding information technology and living technology; and (c) STEAM practice in elementary and secondary schools requiring students to participate in a 2-day elementary STEAM camp or to be involved in a STEAM practicum in secondary schools. The total duration of the pre-service STEAM teacher certificate program takes 36 hours to complete. Finally, students have to finish the STEAM education demonstration and upload their portfolio for evaluation to receive the STEAM teacher certificate.

The course arrangement for the in-service STEAM teacher training program is divided into four levels (Table 5). STEAM teacher professional development in level 1 includes the introduction of the philosophy of Tsinghua STEAM School and curriculum models, practices on STEAM activity and evaluation development, and technology applied in STEAM education; the total duration is 36 hours. After finishing level 1, teachers need to participate in a STEAM practicum for 18 hours in level 2 to demonstrate their STEAM teaching ability. The organization awards the STEAM teacher certificate if their qualification is approved. To ensure the STEAM teachers keep their knowledge and competency up-to-date, Tsinghua STEAM School requests that teachers finish levels 3 and 4 to uphold their STEAM teacher qualification. That is, teachers need to attend the STEAM education on-going training courses twice (24 hours) and share STEAM teaching experiences for at least 6 hours in total to renew the STEAM teacher certificate, for example, sharing experiences through speeches or publications.

Table 4 Pre-service STEAM teachers certificate program

Pick one of two	Theme-A	(a) STEAM education specified course
		(b) STEAM teaching method course
		(c) STEAM practicum course
	Theme-B	(a) STEAM workshops
		(b) STEAM online micro-courses
		(c) STEAM practice in elementary and secondary schools
Mandatory Courses		(d) STEAM education demonstration
		(e) Portfolio evaluation

Source: Tsinghua STEAM School, 2019.

Table 5 In-service STEAM teachers certificate program

Levels	Courses	Duration
Level 1	STEAM teacher professional development	36 hours
Level 2	STEAM education practices	18 hours
Level 3	STEAM education on-going training courses	24 hours
Level 4	STEAM education experience sharing	6 hours

Source: Tsinghua STEAM School, 2019.

In addition to the degree and certificate/diploma programs for STEM teacher education, many short-term training courses help in-service teachers to gain knowledge and competency in STEM education in a short period of learning. NTPC STEAM, for example, has been supported by the Education Department of New Taipei City Government since 2019 and invests great effort in promoting STEAM education and cultivating STEAM teachers. The goals of establishing NTPC STEAM are to tutor 500 STEAM interdisciplinary teachers and STEAM schools in 5 years and to hold STEAM parent-child activities to enhance civil interest in STEAM-related fields. STEAM teacher training courses developed from NTPC STEAM comprise introductory courses for 18 hours (a 3-day training course) and advanced courses for 36 hours. Theoretical and practical content is arranged in the introductory courses; for example, introducing STEAM education and STEAM literacy allows teachers to improve their cognitive STEAM knowledge; and design thinking activities are to strengthen teachers' ability to design and implement STEAM activities. For detailed course information, please refer to Table 6. After finishing the introductory courses, teachers can select various themes in advanced courses according to their interests such as robot programming or optical teaching aids design. In 2019, about 200 STEAM teachers had completed the training courses and started designing STEAM activities for students, indicating effective results of NTPC STEAM.

Other than the training courses organized by NTPC STEAM, attending workshops is another accessible way for teachers who commit to implementing STEM education but have little time to train due to their busy schedules. STEM teacher training workshops, in general, only take a few hours to a day to complete. NTPC STEAM as well as Maker and Technology Centers have been contributing to developing STEM teacher training workshops for the purpose of enhancing teachers' understanding of the importance of STEM education and abilities to design appropriate STEM activities that meet students' learning needs. Most of the workshops are practice-oriented, which emphasizes improving teachers' teaching skills such as creating STEM activities, preparing detailed lesson plans, acquiring knowledge of specific themes, and so on. A 3-hour training course is an example: the course, regarding the theme of solar power application, first begins with introducing solar power application in daily life and the principle of power transportation, followed by circuit assembly and testing with solar power; finally, a solar power hands-on activity is arranged to give teachers opportunities to experience the STEM activity of solar power application (Maker & Tech, 2022).

In other words, the practice-oriented workshops focus attention on training teachers in teaching skills to implement STEM education by providing them with various themes of STEM training courses. Teachers who desire to learn more about STEM issues and trends can also sign up for workshops related to STEM education theory or the latest changes in STEM education such as STEAM x Talk. STEAM x Talk is one of the workshops and is similar to a Ted Talk. In 2020, STEAM x Talk invited seven outstanding STEM educators to share their teaching experiences as well as perspectives on STEM education, and the participants involved hundreds of educators, teachers, and parents (The Education Department of New Taipei City Government, 2022). In summary, the development of STEM teacher training has gradually received increasing attention; for this reason, it is expected that education programs for pre-service STEM teachers and training courses for in-service STEM teacher professional development will construct a thorough STEM teacher education system in the near future.

Table 6 Schedule of NTPC STEAM introductory teacher training courses

Day	Course
Day 1	STEAM education and STEAM literacy
	STEAM teaching and activities design
	STEAM modules in different countries
	STEAM activities development
	Evaluation in STEAM education
Day 2	STEAM workshops: experiencing STEAM activities
	STEAM implementation
Day 3	Design thinking hands-on activities
	Design thinking in STEAM teaching

Source: The Education Department of New Taipei City Government, 2019.

Trends and Issues in STEM Education

The following section introduces the trends and issues in Taiwan's STEM education. Trends refer to the development and change in STEM education. Issues are summarized to present essential topics or problems in STEM education that need to be discussed.

Trends

1. Cultivation of female talent in STEM fields

A report from the Industrial Development Bureau (2021) showed that the percentages of females in STEM-related departments (including undergraduate, graduate, and doctoral schools) were 14.7% in science, 27.5% in technology, 30.2% in engineering, and 31.7% in mathematics. The results indicate a low proportion of female students majoring in STEM fields in Taiwan. These results raised concern about the shortage of female talent in STEM fields. The possible reason is that schools provide little assistance for STEM career exploration, and the gender stereotype makes female students misunderstand STEM careers. To increase the low proportion of female STEM professionals, STEM education is an efficient way of improving female students' affection for learning STEM or intention to pursue STEM careers (González-Pérez et al., 2020). A program called Gender in Science and Technology funded by the Ministry of Science and Technology has committed to increasing female STEM talent. To achieve this purpose, STEM-related activities are held for K-12 female students, such as female science camps, workshops, and speeches, to encourage them to learn STEM and further enhance their willingness to be involved in STEM careers in the future. Moreover, the Education Department of Taipei City Government (2021) collaborated with six Maker and Technology Centers to arrange female STEM online workshops for elementary and secondary school students (female students have the priority to register) for the purpose of cultivating female students' STEM literacy. Recently, efforts have been made to cultivate female STEM talent, and the topic of encouraging female students to pursue a STEM career will continue to be discussed in the future.

2. Organizations and institutions help with developing STEM teacher training

Teachers' teaching ability has been a crucial factor that might be strongly related to their STEM teaching intention (Lin & Williams, 2016; Yu et al., 2021); thus, developing teacher training courses for pre-service teachers and professional development courses for in-service teachers has been widely discussed. For the existing degree programs in Taiwan, National Tsing Hua University is the only institution in higher education that offers a master's degree in interdisciplinary STEAM Education. The applicants need to be in-service teachers who have teaching experience of over 2 years. Courses of the master's degree cover three aspects: research methods, research on theory and issues of interdisciplinary STEAM, and practices of interdisciplinary STEAM education. Apart from that, Tsinghua STEAM School is an organization set up by the government and a higher education institution that is responsible for arranging certificate training courses for pre- and in-service STEM teachers. The certificate training courses include both theory-based and practice-based courses. Finally, in-service teachers can also sign up for training courses or workshops from many organizations and institutions. NTPC STEAM as well as Maker and Technology Centers are two main groups that make great efforts to train teachers' teaching ability in STEM education. In addition to the abovementioned information, an international doctoral program in integrative STEM education at National Taiwan Normal University aims to fill the STEM educator shortage. Although the doctoral program generally focuses on students' research talent in STEM education, it can be seen that cultivating STEM teachers and educators is becoming more important in higher education. To promote STEM education in Taiwan, it is imperative to design more STEM teacher training programs for pre- and in-service teachers.

3. Great attention on STEM learning outside schools

The entrance examinations have a substantial influence on the education system in Taiwan, leading to the over-weighted emphasis on subjects such as Chinese, English, Mathematics, Science, and Social Studies. Besides, little content related to STEM education was mentioned in the latest released 12-year basic curriculum guidelines; therefore, teachers sometimes find it challenging to implement STEM education in formal education due to the lack of time allocation. On the other hand, STEM education in non-formal education has experienced increasing growth over the past decade. STEM activities outside schools such as STEM camps in winter or summer vacations, STEM-related competitions, and exhibitions in museums, provide more opportunities for students to explore their interests and career development (Miller et al., 2018; Robert et al., 2018). Moreover, students are asked to learn everything from the textbooks in formal education, but in non-formal education, they can choose the themes they are interested in. For instance, STEM competitions help cultivate students' collaboration skills when they work with teammates, the ability to identify contexts and conditions when encountering problems, critical thinking skills when collecting and analyzing information or data, hands-on skills when designing and making, and so on. Another issue is that students have no experience or understanding of engineering until they enter a college/university and major in engineering. Therefore, non-formal STEM education plays an important role for students to learn about engineering to see if they are interested in majoring in relevant fields or even exploring their career interests in STEM fields.

4. Proposal of a well-structured STEM instructional design model

A structured instructional design model has been shown to be beneficial for teachers' teaching (Anderson & Goodson, 1980) and enables teachers to bridge the gap between theory and practices by following a series of steps (Smith & Ragan, 2004). Teachers may learn the concept of STEM education or have experiences with STEM activities if participating in training courses; however, creating a STEM activity is still a challenge if they have doubts about where to start. Different frameworks or models have been presented in studies to demonstrate a perspective on STEM education, but none of them show where to start to design a STEM activity. Since teachers are usually unfamiliar with planning interdisciplinary activities, a structured STEM instructional design model is essential for giving teachers clues about how to generate STEM activities as well as enhancing their confidence and intention in conducting STEM education. Ku et al. (2022) proposed a six-stage integrated STEM instruction design model with explicit tasks that teachers must accomplish in each stage. The stages start with preparation, followed by analysis, design, planning, implementation, and evaluation. Besides, the 25 tasks were generated as a checklist to remind teachers what to do in the six stages. The aim of the six-stage integrated STEM instruction design model is to outline essential components of STEM education, for example, teacher team building, background analyzing, authentic context designing, students' learning experiences planning, teachers as facilitators, and continuity of evaluation. Moreover, the model presents a guideline for STEM teachers or educators to apply in their teaching processes.

5. Development of an assessment system in STEM education

Speaking of assessment in education, cognition, affection, and skills are three dimensions that are frequently mentioned; however, STEM education, unlike regular disciplinary education, tends to place more attention on students' abilities to integrate and utilize interdisciplinary knowledge and skills to solve problems relating to the real world. In this case, an assessment used in STEM education must be more than just assessing students' knowledge, affection, and skills; instead, an instrument that can examine if students are able to integrate what they have learned to solve problems is needed. Gao et al. (2020) analyzed 49 papers to explore the existing assessment of STEM learning, and the results revealed the lack of a valid and reliable measurement instrument to examine students' learning outcomes in STEM education. Accordingly, Lin et al. (2022b) developed a students' context-based STEM competency online assessment for teachers to understand students' performance of STEM problem-solving competencies, including contextualization, predictive evaluation, analogical reasoning, quantitative thinking, and reflective ability. The competencies are related to cultivating high-order skills which meet STEM professionals' requirements. Results of the context-based assessment show evidence of students' learning efficiency after taking STEM education, and help teachers to reflect on and further adjust the teaching process. Even though the research is ongoing, the context-based STEM competency online assessment contributes to adopting a new perspective on assessing students in STEM education.

6. Applying digital devices in STEM education

Due to the development of technology, digital devices have been widely used in STEM education for teaching and learning. Gao and Sun (2020) as well as Wang et al. (2022) summarized relevant studies relating to the effects of using digital games or devices in STEM education, and indicated a positive result. An adaptive learning system built by the Ministry of Education is an online teaching platform that supports elementary and secondary school students' learning with digital technology. The system provides over 7,000 teaching and learning materials, including text, pictures, videos, and tests for different disciplines. Notably, the artificial intelligence (AI) technique is adopted to analyze each student's condition and provide proper learning aids. The primary rationale for designing the adaptive learning system is a concern about students having different learning paths. Students' learning efficiency differs because of their capital backgrounds; in this case, teachers find it challenging to teach students with varying needs with unified instruction. Accordingly, using digital supports such as the adaptive learning system helps teachers arrange diverse teaching assistance for their students to achieve their learning goals. Besides, other digital devices, for example, computers, mobile devices, whiteboards, projectors, Web 2.0, and robots, have been applied as educational technologies in classrooms, suggesting a trend of using digital devices in STEM education.

Issues

1. Lack of STEM education goals and policy

According to the number of studies regarding STEM goals or policy, it was the top research topic between 2000 and 2018 (Li et al., 2020), showing great attention to discussing STEM goals and policy worldwide. Williams et al. (2015) further pointed out that one of the issues when implementing STEM education is that the goals and purposes of STEM education are usually fuzzy. STEM goals and policy-making differ in different regions; for instance, STEM education in the United States emphasizes improving students' achievement in science and mathematics fields and cultivating STEM-related professionals. On the contrary, Lin's (2018) report on STEM education trends in Taiwan proposed a problem of lacking goals for STEM education that needs to be discussed, meaning that there is a gap between policy-making and practices of STEM education in K-12. As mentioned in the previous section, there is only a little information relating to STEM education in the latest curriculum guidelines; however, supports from government or school administrators have been proved to be a factor that might positively relate to teachers' intentions to implement a new or unfamiliar curriculum such as STEM education (Margot & Kettler, 2019; Yu et al., 2021). As a result, the details of STEM goals need to be rigorously discussed to make a systematic STEM policy for the purpose of improving teachers' willingness to implement STEM education and promoting STEM education at all levels of education.

2. Lack of systematic STEM teacher education programs in higher education

A report on research trends of STEM education found that the Journal of STEM Teacher Education published a significant number of studies between

2007 and 2017; besides, the topic relating to professional development was popular in the same period (Chomphuphra et al., 2019). The results of Chomphuphra et al.'s study revealed the importance of STEM teacher education. Researchers have also indicated that to enhance teachers' intention to conduct STEM education, organizing teacher training programs for pre- and in-service teachers to improve their confidence and positive perceptions is essential (Lin & Williams, 2016; Yu et al., 2021). Although several teacher training programs have been developed to support STEM teacher education, two out of three degree or certificate programs target in-service teachers' training; besides, the existing short-term training programs are rich but lack systematic organization. Other concerns such as the importance of teachers' maker-based technological pedagogical content knowledge (TPACK) (Ku et al., 2021) and ability to use technology in STEM education (Kang et al., 2021) have been highlighted as crucial teaching abilities which should be taken into consideration when making course arrangements for STEM teacher education. To sum up, a call is proposed to develop STEM teacher training programs for pre-service teachers in higher education institutions, especially at normal universities.

3. Teachers' challenge of adopting hands-on activities in online STEM education

Many discussions about the pros and cons of remote teaching or online learning were raised when the Covid-19 pandemic hit the global community. Apart from the ability to appropriately implement lesson plans through online software, studies from Code et al. (2020), Kang et al. (2021) as well as Makamure and Tsakeni (2020) brought out teachers' questions on adopting hands-on activities or practical usage of technology tools when doing remote teaching, a concern which often arises in STEM activities. Our teachers were challenged to deliver online courses due to the epidemic raging in 2021. Lacking remote teaching experiences, teachers found it frustrating when teaching hands-on courses. Accordingly, the need for training teachers' capabilities for remote teaching, such as online software applications or hands-on activities planning for online STEM education, is increasing not only for the post-pandemic period but for all future education environments.

4. Lack of varied STEM interdisciplinary modules

As presented in the above section, an increasing number of STEM-related activities have been designed for formal or non-formal K-12 education ever since STEM education became a favored topic in Taiwan. Nonetheless, several issues are noticed when we look into the existing STEM modules; for example, STEM disciplines are taught silos with different teachers in some STEM modules without cultivating students' integrated interdisciplinary competencies; the same STEM module is conducted at various educational levels without considering students' differences; the features of STEM career exploration are generally omitted when designing STEM modules. Lin (2018) suggested that varied STEM interdisciplinary modules must be developed to cultivate STEM talents that meet the needs of different STEM-related careers.

5. Diversity issues in classrooms

Diversity issues might have a strong influence on students' STEM learning, such as their STEM identifies or attitudes toward pursuing a STEM career. The issues of race and gender differences in STEM education have long been discussed; for example, Saw et al. (2018) found that diversity affects high school students' interest in STEM careers, and Jong et al. (2020) indicated that students' various backgrounds must be considered in STEM education. In Taiwan, the gender issue has attracted attention; however, the issue of new immigrant children has not yet received enough attention, either in disciplinary or interdisciplinary education. New immigrants, as defined by the Ministry of the Interior, refer to people from other countries (mainly from China and Southeast Asia) who married Taiwanese. A report published in 2018 showed that over half of the new immigrants did not hold an educational achievement higher than high school. Some immigrant children could find it difficult during learning or could have low learning achievement due to speaking a different native language or because of a lack of parents' assistance. According to the survey conducted in 2021, the population of new immigrants reached 570,000 in Taiwan (2.4% of the population). As a result, teachers are facing the challenge of designing STEM courses considering diversity issues regarding gender and new immigrant children. Referring to the research results of Singer et al. (2020), it is evident that STEM activities based on the consideration of diversity could provide students with authentic learning experiences, allowing them to develop positive STEM identities as a scientist; therefore, more STEM-related activities are suggested be designed for the purpose of addressing the diversity issues in classrooms.

Conclusion

Recently, the increasing shortage of STEM talent in Taiwan has brought a focus on STEM education. This chapter provides an introduction to the status of STEM education development in Taiwan, including the contexts and history of STEM education, the goals of implementing STEM, STEM-related activities in formal and non-formal education, evaluation in STEM, and STEM teacher education; besides, the trends and issues regarding STEM education in Taiwan are also detailed to present some changes and further concerns.

Integrated education was first described in the Grade 1-9 curriculum guidelines, combining science and living technology into one domain. In the latest 12-year curriculum guidelines, STEM is viewed as interdisciplinary education which is specifically allocated to the technology domain of the upper secondary school stage. Although STEM policy stays fuzzy and the latest curriculum guidelines for K-12 students do not include many details relating to STEM education, a consensus on STEM education goals was agreed upon by secondary in-service teachers in a relevant study (Lin et al., 2022a) which refers to cultivating students' 21st-century skills, STEM literacy, and capabilities in interdisciplinary problem-solving.

Great attention has been placed on fulfilling the shortage of STEM talent, and thus various STEM-related activities were designed to cultivate students' abilities to utilize learned STEM knowledge and skills to solve problems encountered in their daily life, as well as increase their intention to pursue a STEM career. In formal education, STEM-related activities are usually arranged in a school-developed curriculum that offers alternative courses for students rather than in a mandated curriculum; that is, not every student has the opportunity to participate in a STEM course in K-12 education system. To promote STEM education, the government supports setting up 100 Maker and Technology Centers to design STEM-related activities and provide the modules to K-12 teachers who are interested in conducting STEM education. As for non-formal education, a great number of STEM-related activities, such as camps, clubs, competitions, teaching aids, and exhibitions, are provided by different institutions or organizations.

Many have researched assessment and evaluation in STEM learning; however, little consensus has been reached for decades. Considering students' performance in PISA and TIMSS as well as the STEM education goals, the research team at NTNU has developed a context-based STEM competency online assessment. Contexts designed for the assessment are authentic and real-life problems. With online assessment, teachers understand students' STEM learning performance by examining the five interdisciplinary problem-solving competencies which are difficult to cultivate in disciplinary education. The online assessment results are shown as scores and a Rader chart, allowing students to reflect on their learning processes and giving clues for teachers to assess students' learning efficiency and make adjustments to the next STEM lesson plan.

The development of STEM teacher education includes a master's degree program for in-service teachers, certificate programs for both pre- and in-service teachers, and short-term training programs generally for in-service teachers. The master's degree program is offered by a university, and the certificate programs are developed by the government collaborating with a university. The degree program takes years and the certificate programs take days to months to finish; both aim to cultivate teachers' STEM content knowledge, pedagogy knowledge, and pedagogical content knowledge. On the contrary, most short-term training programs typically focus on teachers' practical teaching skills and only last for hours to a couple of days.

Finally, to conclude the trends of STEM education in Taiwan, several ideas are highlighted. Foremost, efforts have been made by the government and organizations to contribute to supporting STEM teaching and learning, especially in non-formal education; for example, holding activities to cultivate female STEM talent; developing training courses to give assistance to STEM teachers who commit to implementing STEM education; providing various STEM-related activities for students to explore their interests and enhance their willingness to pursue STEM careers; and applying multiple digital devices to help deliver courses. In addition, researchers have been working on bridging theory and practices to help teachers overcome challenges when implementing STEM education, such as designing an easy-to-follow STEM instructional design model or developing an online assessment system for assessing students' STEM learning performance. Apart from that, concerns such as a lack of STEM education goals and policy, the need for a systematic pre-service STEM teacher education program to be developed, challenges in adopting hands-on activities through online STEM education, a call for designing various interdisciplinary modules, and diversity issues in classrooms are also proposed to be further discussed.

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Status and Trends of STEM Education in the United Arab Emirates

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Abstract

As with the reform agendas of many countries in the region, EMEA, MENA, and GCC, the status of STEM education in the United Arab Emirates (UAE) is no different. The UAE has presented steady strategic development towards STEM education and career development. This chapter provides a comprehensive review including deep interpretation of the status of STEM education in the UAE. The growing interest in STEM education in the UAE has resulted in federal policy initiatives and non-government grant programs that advocate for specific educational reforms and provide funding to develop educational experiences and curricula for students. The main findings regarding STEM education as reflected in the major trends are discussed in this chapter: Policy and Reform, Problem-Based Learning, Curriculum Integration, Career Aspirations, Gender Aspects, Professional Development, and Culturally-Embedded Resources. Supporting subthemes include the historical account of STEM education, its theoretical and pedagogical frameworks, and STEM professional development that comprehensively provides discourse of STEM education, its characteristics, and the findings of our key studies related to STEM education in the UAE. Yet, several challenges are also noted: the need for clear STEM strategies, the development of curricula and programs, both at government and private schools as well as at universities, based on real industry applications and sustainable resources that are in the Arabic language and which are culturally embedded.

Keywords: STEM education, STEM status and trends in the UAE, STEM education trends

Introduction

Science, Technology, Engineering, and Mathematics (STEM) education has become a topic of much debate in educational settings over the past several decades (Forawi, 2021). The urgency to enhance improvement and achievement in education related to science, technology, engineering, and mathematics has become evident from the massive number of reform programs that have given all their focus to STEM disciplines and its applications that should meet workplace requirements (Eltanahy et al., 2021). Another cause for changes in STEM education is the difference in the way today's students are motivated (Chittum et al., 2017). The growing interest in STEM education has resulted in federal policy initiatives and non-government grant programs that advocate for specific educational reforms and provide funding to develop educational experiences and curricula for students (Forawi, 2018). Consequently, in the past two decades, STEM education policy documents have established common concern about the United States ability to maintain the highest economic privilege in a global market in which STEM disciplines play a vital role (Forawi, 2017). STEM education integrates concepts that are usually taught as separate subjects in different classes, and emphasizes the application of knowledge to real-life situations. It is indispensably important that STEM education in K-12 schools aligns with 21st century skills, creates new jobs, improves economies, and educates the next generation of STEM professionals (Al Quraan & Forawi, 2019). Many research studies that have been conducted in the region and worldwide have stressed the importance of learning integrated STEM in a logical timeline (Chittum et al., 2017; Eltanahy et al., 2021). They have discussed how STEM subjects are interdependent and related to students' real-life experiences. Moreover, some conference papers have focused on the role of schools, teachers, students, and decision makers in developing and growing integrated STEM education. In Saudi Arabia, for instance, educational initiatives are aligned with these international and domestic orientations toward integrated STEM education in schools. The Saudi National Strategy for Public Education Development Project aims to develop "curriculum, instructional methods, and the assessment process to improve pedagogy" (Al-Muhaisin & Khaja, 2015, p. 6). There are many ways to reach such goals, one of which is to integrate STEM disciplines into education and to relate curricula to 21st century skills (Saudi Ministry of Education, 2010).

Mathematics, science, engineering, and technology are subjects that are believed to reflect people's cultural achievements and which power the economy and development, while at the same time constituting essential aspects of our lives. Educators admit that it is vitally important that integrated STEM education in K-12 schools aligns with 21st century skills, creates new jobs, increases competition in the global economy, and educates the next generation of STEM professionals. The implementation of STEM is at its early stage in the UAE and calls for an integrated framework for effective implementation in K-12 education. In 2014, the United Arab Emirates through the Institute of Applied Technology hosted the fifth International Annual Teaching Technology (IAT TEC) conference. International initiatives to teach STEM disciplines were discussed, and new patterns and technology solutions to teach STEM were represented. These solutions have been described as easing and encouraging the educational processes to motivate students to choose STEM careers in the future as their professional path (Al-Muhaisin & Khaja, 2015). It is at such forums that many ideas to build STEM capacity and develop programs in the Middle East are discussed and shared. To complement the UAE government's Vision 2021, the UAE Ministry of Education implemented an educational development program for mathematics and science as part of improving integrated STEM education (Warner & Burton, 2017). The new initiatives were taken to support scientific literacy and to develop math and science curricula.

The Status of STEM Education in the UAE

UAE Education System and STEM Education

The UAE sits in the north-eastern area of the Arabian Peninsula, bordered by Saudi Arabia to the south and west and by Oman to the east and north. The country is made up of seven emirates: Abu Dhabi, Dubai, Sharjah, Ajman, Fujeirah, Ras Al Khaimah, and Umm Al Quwain. Abu Dhabi is by far the largest emirate, occupying 85% of the UAE landmass. The UAE is unique in the sense that the local native population is a minority. The country has a population of approximately 4.5 million people, of whom less than 20% are native Emiratis. The population is overwhelmingly made up of expatriates from the South Asia region choosing to live and work in this country for limited periods of time; approximately 8% of expatriates are Westerners (Husain, 2022).

Abu Dhabi is an emirate of distinct diversity, terrain, people, traditions, and ambitions. It has a rich heritage governed by a deep-rooted respect for its past, which guides the present and is influencing its future. The late leader Sheikh Zayed bin Sultan Al Nahyan was revered by his peers and adored by the people of this country. As the UAE's president for 33 years and ruler of Abu Dhabi from 1966, Sheikh Zayed was responsible for unifying the disparate emirates and for the major economic and social advances both in Abu Dhabi and throughout the UAE; his vision laid the foundation for today's modern society (Warner & Burton, 2017).

When the UAE was established in 1971, the Emirates had 74 schools, and those choosing to pursue a higher education were obliged to travel overseas. More than 40 years later, the UAE is making progress toward its goal of competing with countries such as China and Singapore, which have invested heavily in establishing top-tier research universities (Mahani & Molki, 2011). From the 1970s to the end of the 1990s, the UAE experienced massive growth in schools, students, and teachers. Following the initial expansion, the qualitative improvement phase focused on public school reforms and the improvement of higher educational institutions. The transition between the educational phases has been rapid. Cycle 2 and cycle 3 enrollment between 1973 and 2009 rose from 22% to 93%. Additionally, literacy rates have soared. In the 1970s, at the founding of the UAE, 48% of adults were illiterate; 40 years later, over 93% are literate (Crown Prince Court, 2011, cited in Molotch & Ponzini, 2019). On an international scale, the UAE can be seen as outperforming its neighboring countries. In 2016, the UAE achieved the highest score amongst all Arab countries in the Progress in International Reading Literacy Study (PIRLS), an international test of reading proficiency. Despite all the academic achievements attained in such a short timeframe, there is still, however, room for further growth. On an international scale, the UAE does not meet the international average for student achievement (Gallagher, 2019).

A number of foreign universities have been attracted to the UAE by what they believed to be easy money generation in a wealthy country (Warner & Burton, 2017). Consequently, they failed to perform their due diligence regarding setting up a campus in the UAE and proceeded without adequate market research. Knight and Bennett (2019) alternatively argued that universities not in the for-profit sector are more typically motivated by the desire to expand their research and knowledge capacity and to increase cultural understanding.

The National Plan aims for the UAE to achieve a leading position in creating a cohesive society that values the preserved identity and the unique culture and heritage of the Emirates. Ideally, STEM has the potential to permit innovative ways through which the beliefs and values can be preserved; this can be done by learning about cultural identity, thus leading to the learners preserving their traditions. It also aims to place the UAE among the top destinations that promote and manage entrepreneurship initiatives at various levels, and make its nationals active participants in the economy of the country. Furthermore, the Agenda goes all-out to implant an entrepreneurial culture in schools and universities to nurture leadership, innovation, creativity, and ambition. This will ensure that the UAE follows bold steps towards becoming among the best in the world in terms of luxury, happiness, and business development (National Research Council, 2014).

Education also has its place in the heart of the National Agenda. Smart systems and devices are the basis for all projects and research. An emphasis has been put on the development of a holistic model of successful citizens of the future in order to shape their personalities and their future. Given that broader context, policy makers forcefully argue that to ensure human development, analytical experts should understand the policy and an implementation framework for STEM in UAE schools (Tabari, 2014).

The education system of the UAE is currently going through a period of remarkable educational reforms. Over the last few years, the UAE has pursued policies which are in correspondence with not only its neighboring countries, but with the wider Middle East and MENA (Middle East and North Africa) region as well as most of the countries around the globe. Through UNESCO and the OECD, the nation is pursing global education reforms (GERM) to enhance the quality of and access to education in UAE public and private schools. Also, there has been widespread expansion of private and public schools as well as other educational opportunities such as virtual education or distance learning which have also further pushed the efforts towards educational reforms in the UAE. The World Bank (2014) pointed out that the MENA region has achieved several milestones in its educational reforms including reducing illiteracy, an increased focus on science and technology education, increased access to the point of universal education for both males and females, thereby reducing the gender gap where any gender was outperforming the other, and greater financial investment and support from businesses, industries, and local governments (Warner & Burton, 2017).

In pursuit of UAE Vision 2021, Highness Sheikh Mohammed Bin Rashid Al

Maktoum announced a mechanism in 2014 to achieve the National Agenda. The central objective behind the National Agenda is to establish a first rate education system in the UAE through which both private and public schools will be converted into small learning environment platforms where both theory and practice are taught. There are eight pillars of this National Agenda which are considered as foundations for the future development and reforms of education in the UAE. These seven pillars are: "education, healthcare, economy, police and security, housing, infrastructure and government services" (Warner & Burton 2017, p. 16). Education, as the most important of these pillars, further includes eight indicators which will monitor the progress towards achievement of the National Agenda. These eight indicators are:

> (1) To be among the top 20 countries with highest performance in the Program of International Student Assessment (PISA) test, (2) To be among the top 15 countries with highest performance on Trends in International Mathematics and Science Study (TIMSS), (3) To ensure that all schools (public and private) in the UAE have high quality teachers, (4) To ensure that all schools (public and private) have highly effective leadership, (5) To ensure that 90% of students in the ninth grade of public and private schools have proficiency in Arabic, (6) To increase the high school graduation rate to 98% among Emirati students, (7) To provide early years education to 95% of children between age 4 and 5 through public and private preschool provisions, and (8) To eliminate the need for Emirati students to have to complete a foundation program to qualify for university entry (Warner & Burton, 2017, p. 1).

The educational reforms of the UAE are inherent within these above indicators which focus on better preparation of students in schools at all stages of their education, high standards on an international scale, greater accountability among teachers and school leaders in the sector, and improved professionalism among teachers. These goals can, therefore, be summarized into four categories, as illustrated in Figure 3 below. These goals are considered the obvious synergies among the above eight indicators for the educational reforms in the UAE (Warner & Burton, 2017).

The goals of STEM education in the UAE are reflected in the main government's reform agendas and the related published studies, as presented in this section. STEM education has been introduced formally and informally in UAE education over the past few years with light focus and coverage (Mahil, 2016). However, the demand of STEM in UAE education has increased recently due to the government response to UAE Vision 2021 as well as to meet the expectations of a diverse economy which is calling for more STEM-related professions and sectors in the UAE economy, especially in burgeoning sectors such as scientific investigation, engineering, and renewable energy in the country. Makhmasi et al. (2012) pointed out that the recent STEM initiatives in the country such as the "Innovation Hub," which was launched by the Al Bayt Mitwahid Association in collaboration with Google, has given a great deal of media coverage to STEM education in the UAE. The project was launched in Ras Al-Khaima emirate with a focus on introducing a STEM+ lab curriculum into the schools. Makhmasi et al. (2012) pointed out that this is also considered to be the first official STEM initiative in the UAE.

With the concentrated efforts of the UAE government to strengthen and diversify its oil-based economy, the country has seen a surge in educational reforms which were highly concentrated on teaching science, technology, engineering, and mathematics subjects. Projects like the Smart Learning Programme (SLP) with a similar, albeit more ambitious, vision, have also been introduced in the recent past; however, schools in the UAE require more practical knowledge of science and technology subjects, thereby making room for STEM educational reforms (Pennington, 2014). Compared to other Middle East countries, the UAE is not a leading contributor to technology and science developments given its economic and regional importance. While there have been continuous discussions over the nature, scale, and extent to which there is a lack of science and technology developments, the majority of experiences have a common consensus that the problem is real and growing with the passage of time. Because of the reducing trend of STEM in the UAE, it is believed that students are mostly enrolling in degrees which are not fruitful for the development of the country, and that this will ultimately affect the workforce available for businesses and industries. Hence, under the UAE Vision 2021, the UAE educational system needs to evolve, and must provide highly talented STEM workers to reach its vision of becoming an innovative and self-sustaining economy. Through concerted efforts aimed at diversifying and strengthening the rising oil-based economy, the UAE has begun revamping its education system, particularly the STEM subjects (Makhmasi et al., 2012). However, Makhmasi et al. (2012) asserted that while STEM subjects are taught by teachers and schools with utmost vigor, interest, and high aspirations, it does not ensure that students will enroll and major in STEM fields and will become productive and innovative members of STEM professions. This is due to the many challenges and barriers which might influence the choice of students to study for further education and for future career aspirations. Yet, private schools seem to be taking the lead in introducing and implementing STEM subjects compared with government schools, as the private schools are based on different international curricula and accreditations; STEM education is recognized as part of these curricula. Hence, it is important to cross this bridge by bringing more awareness of STEM to UAE society through an integrated STEM education framework which focuses on all stakeholders in the society (Makhmasi et al., 2012).

Because there is a dearth of available in-depth literature and studies regarding STEM in the UAE, the current research can be considered as a starting point that intends to determine the policy recommendation for the implementation of an integrated STEM Framework in UAE schools, and thereby intends to address the gaps and the quality issues by understanding STEM advancement, mainly in areas such as stakeholders planning for interconnectedness between sectors and partnership with the community and other sectors' curriculum and level of integration, STEM job skills and competencies, teachers' preparation and professional development, delivery, and workforce demands.

The new curricula are based on McGraw Hill Education's textbooks which were translated and adapted to the Arabic language and culture (Sahoo, 2016). "The UAE Ministry of Education has signed a seven-year deal with the American company McGraw-Hill Education to procure all K-12 mathematics and science instructional materials in e-book and print formats" (Sahoo, 2016, p.1). This initiative has resulted in several movements toward applying STEM education in the UAE. All integrated STEM education initiatives in the UAE are so far "exclusive to private educational institutions and have not yet reached public education and government schools" (Sahoo, 2016, p. 1). The government is however taking logical steps to expand integrated STEM education to public schools, entailing changes that would affect teachers, students, administrators, and curricula in the UAE. In the UAE, "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" (Sahoo, 2016, p. 1). Likewise, "UAE mathematics teachers are not automatically qualified to teach integrated STEM disciplines" (Sahoo, 2016, p. 1), which aligns with Bennett and Ruchti's (2014) statement about teachers regarding content: "Many teachers are not content experts within each of these disciplines and bridging these individual fields can be a challenge" (Bennett & Ruchti, 2014, p. 17). Since teachers and stakeholders are key players in the educational process, it is important to examine the perspective of teachers and stakeholders regarding STEM integration and implementation by discussing points of STEM pedagogical content knowledge, thoughts, attitudes, needs, and obstacles that can challenge them to successfully implement integrated STEM education in their classrooms. The UAE ranked among the top 15 countries in the IMD World Competitiveness Ranking 2021 to be included in the 10 countries in this book.

This chapter is presented in four main sections: introduction; needs and reforms; practices; and the way forward for STEM education in the UAE. Therefore, this chapter presents three main clusters of themes, namely Needs and Reforms of STEM Education in the UAE, UAE STEM Education Practices and Challenges, and the Way Forward for STEM Education in the UAE with some supporting subthemes: the historical account of STEM education, its theoretical and pedagogical frameworks, and STEM professional development that comprehensively provides discourse of STEM education, its characteristics and related key study findings in the UAE.

The following section provides aspects of the status of STEM education in the UAE through three main foci, namely a historical account of STEM education, its theoretical and pedagogical frameworks, and professional development.

Historical Account of STEM Education

STEM education has a long history in different parts of the world. In the United States, for example, it dated back to the Morrill Act of 1862 that was introduced to improve agriculture and work skills through the creation of land grant universities, but it had the additional consequence of developing science and engineering programs in all states (Al Quraan & Forawi, 2019). The next big change in education policy related to STEM education happened in 1957 with the launch of Sputnik by the Russians, followed by the National Commission on Excellence in Education's "A Nation at Risk" report released in 1983, relating to less emphasis on mathematics and science.

This report again changed the educational landscape. It called for higher graduation requirements in core subjects including math and science. It recommended that K-12 and higher education adopt more “rigorous and measureable standards” and that expectations for student performance and conduct be raised. The standards movement stemmed from this report, and subsequently the National Council of Teachers of Mathematics developed the Curriculum and Evaluation Standards for School Mathematics (NCTM, 1989) and the National Research Council established Benchmarks for Science Literacy, National Science Education Standards (National Research Council, 1996). Later, the term “STEM” entered the common vernacular when Dr. Judith Ramaley, assistant director of the Education and Human Resources Directorate, first used it while at the National Science Foundation in 2001. Previously, the acronym was “SMET” which did not have the positive connotations of the STEM acronym, and which subtly implied that science and mathematics were better than technology and engineering. Since then, the term “STEM” has spread far beyond the NSF.

One theme presented in these varied reports is that STEM education can lead an individual to employment that is valuable and important to the nation’s ability to be innovative. Another conception is that “people need to have a degree of technological literacy to be productive citizens whether they work in STEM fields or not” (National Academy of Engineering [NAE], 2014). This report by the National Academy of Engineering illustrates why STEM education is seen as being critical to the prosperity of the United States in the future. According to the NSF, NRC, and NAE, the goal and standards of STEM education ensure that students acquire the learning required to understand how to manage natural resources, make meaningful decisions, and function in the world as responsible citizens (NRC, 2011; NSF, 2016). “Drawing on research findings from fields such as neuroscience, cognitive science, social psychology, and human development” (p. 54), the United States government affirmed that literacy in the STEM disciplines is the driving force of technological advancement for the infrastructure needed to secure economic success in a competitive and innovative world. To meet the expectations of STEM education and to prepare students to function successfully in the workforce, the United States Common Core policy is taking instruction in this direction (CCSS, 2012).

A review of the Common Core standards developed by many states across the United States was also a point of research in the literature review. The Common Core Curriculum standards (CCSS) increase the rigor and raise the educational expectations to align with college and career readiness. Standards that sweep across the United States ensure that all students, regardless of where they live or go to school, are exposed to and taught a unified set of skills and information. The Common Core curriculum initiative has created a common expectation of what students know, understand, and are able to perform.

While the implementation of the Common Core curriculum has intended positive outcomes for students and the educational system in the United States as a whole, there are other residual effects to its enactment. Evans, Executive Director of the National Science Teachers Association (NSTA), stated that the Common Core will change the way teachers must instruct, and finding appropriate professional development to support the changes will be a challenge. This paradigm shift in instructional practice will require greater content knowledge expertise and advancements in pedagogy. It was observed that teachers needed more time to collaborate to unpack standards, analyze lessons, and understand what the new instructional practice looks like.

The Common Core Curriculum is not a defined curriculum blueprint but instead a framework of expectations to prepare students to be college and career ready. Thus, countries like the UAE adapted the CCSS, especially in the K-12 private schools, to standardize the curriculum with more rigorous content expectations coupled with higher levels of knowledge application which will prepare students to meet the demands of the new 21st century world. Such curriculum aims have paved the way to the integrated STEM education initiatives as an attempt to incorporate all STEM disciplines into one course or other combinations as discussed based on Vasquez et al.'s (2013) model in Figure 1 in the subsequent section.

This historical account is also supported by Kelley (2012) who argued that "the history of technology education, engineering education" and the current STEM education movement are very similar. Kelley (2012) outlined a three-pronged structure that provides a history of how the current STEM subject integration approach to education has occurred. His three prongs include design-based education, project-based education, and subject integration. Kelley (2012) argued that design-based education is one of the structures that has led to the current integrated STEM movement. Design-based education is based on the work of Heinrich Pestalozzi from the early 1800s who believed that children should be educated in a wide range of real-life situations using a hands-on approach (Kelley, 2012). Later in the 1800s, Fredrick Froebel, who was the father of modern day kindergartens, built on Pestalozzi's work which was greatly influenced and inspired by Froebel's initial thoughts and practices. Froebel created a line of children's toys that were boxed sets of blocks designed to teach children about symmetry and beauty. Frank Lloyd Wright played with Froebel's blocks and recalled them as formative. Wright believed that the Froebel blocks were critical to helping develop his design abilities. Design-based education was further championed by Frederic Bonser and Lois Coffey Mossman in the early 1900s when both of them emphasized the "need for students to design their own projects" (Kelley, 2012, p. 6).

The second prong in the history of the integrated STEM education movement was project-based education. Its roots can be discovered at the Van Rensselaer Polytechnic Institute where practical applications of science and mathematics led to the "founding of a department of Mathematical Arts in 1835 for the purpose of giving instruction in Engineering and Technology" (Mann, 1918, p. 12). Another "American school of engineering" that combined the theory and practice of engineering was the Worcester Technical Institute in Worcester, MA. It introduced the use of vocational skills to complete projects as part of the curriculum (Kelley, 2012). Project-based learning continued to grow during the 20th century with the work of Kilpatrick and Dewey. Their approaches to learning argue for meaningful task-like, case-based instruction and project-based learning (Dewey, 1938). Project-based learning has continued to remain a focus in education studying the complexity of engineering design and how it is best taught. Project-based learning is the most favorable approach to be used in schools in the UAE. Another approach that has gained importance in delivering good STEM experiences in school is the inquiry-based learning which has a long history in the reform agendas in the UAE and other parts of the world. In the Czech Republic, for example, teacher training is an activity that has been decentralized, with universities having an augmented degree of autonomy. In this regard, universities have established novel methods to instigate initial teacher learning to strengthen the conception of the inquiry-based technique. This aspect is founded on the Hejny method, which is associated with mathematics at the primary level. The Hejny method is aimed at allowing children to discover math by themselves and to enjoy the process (Al Quraan, 2017).

The third leg of the STEM integration platform is subject integration, pioneered by Lois Coffey Mossman, who wrote that "integration of school subjects could be accomplished through practical classroom activities" (Kelley, 2012, p. 4). In order to study the category of STEM education, the framework for STEM education outlined by Kelley (2012) will be used. Kelley argued that three different educational movements: design-based education, project-based education, and subject integration, have been combined in the form of today's STEM education. This framework was chosen because it fits the problematic nature of STEM education found by Pitt (2009). Project-based learning aligns with the concept of transfer of knowledge. Design-based education addresses pre-vocational learning and training. Finally, subject integration crosses the boundaries between STEM subjects. Subject integration again came to the forefront in the Math/Science/Technology (MST) movement of the 1990s. The MST approach improves the status of technology education by its incorporation into the core subjects. Subject integration/project-based learning/design-based education are the backbone pedagogical methods for integrated STEM, and professional development would provide the necessary training. Specific evidence related to these links can be found in the "subject integration/project-based learning/design-based education" and professional development categories that are developed in the structural implementation categories section (Al Quraan, 2017).

Theoretical and Pedagogical Frameworks of STEM Education

STEM education has been the center of attention in education, and has mainly involved successful strategies to organize students for effective, higher quality learning in the STEM-related industry. To come up with an effective cross-disciplinary field, it is necessary to revisit the theories of Dewey (1938) and Capraro et al. (2013) to observe how their work relates to STEM education. Relying on the thoughts of these theorists and the individuals that contain prolonged on their work, this chapter will illustrate the individuality of effectual STEM learning fields with a focal point STEM strategy implementation. Purposely, we will dispute that for the instructional situations to be successful, they must significantly put together the STEM fields, support cooperation, offer students a genuine and real-life environment in which to employ STEM content, and moreover allow students access to the concepts and give them confidence to articulate the concepts in various modes of representation. Table 1 shows four different levels of subject integration: disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary.

Table 1 Increasing levels of integration

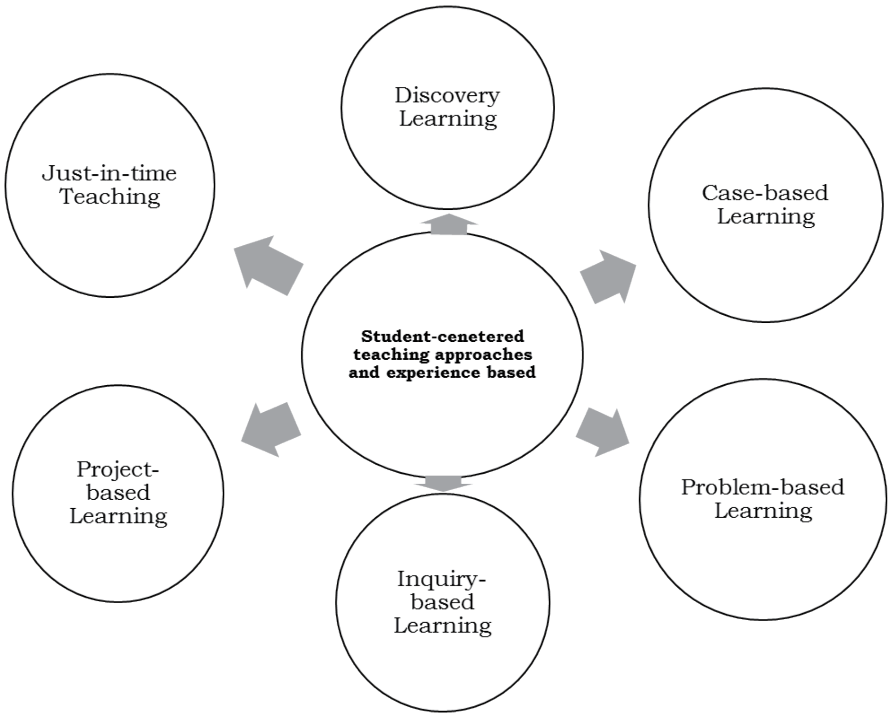
Form of integration	Features
1. Disciplinary	Concepts and skills are learned separately in each discipline
2. Multidisciplinary	Concepts and skills are learned separately in each discipline but within a common theme
3. Interdisciplinary	Closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills
4. Transdisciplinary	Knowledge and skills learned from two or more disciplines are applied to real-world problems and projects, thus helping to shape the learning experience

Source: Vasquez et al., 2013.

Dewey provided the theoretical framework that makes the most of the relations between the disciplines in incorporated STEM lessons or schools during the operation and explanation of theory. Dewey (1916) was very cautious about making it clear that he was not advocating career training. As he states, "the only adequate training for occupations is training through occupation" (Dewey, 1916, p. 297). In this approach, instead of testing students with uncomplicated, simplified problems, students are given multifaceted, realistic problems that are "simulations of real life experiences." Dewey believed that students' tribulations in school must be based on the existent life situations, but all these theorists agreed that students must work collaboratively. Nevertheless, each theorist reached it from a slightly dissimilar point of view. For Dewey (1916, 1938), education is communal in nature and serves a purpose within a democratic system. Therefore, students are supposed to proceed and deserve to be considered as members of the public, and have the same immunity for the representative of an independent society, requiring them to work mutually as public students. Authentic interdisciplinary problems exterior of school are frequently approached by groups, especially when different areas of expertise are needed to solve the problem. For this reason, it is reasonable for students to also move toward their problems in groups. Adding to this cooperation also adds the advantage of improving communication and metacognition.

Capraro et al. (2013) stated that there are several approaches to developing and implementing STEM education. They are indicated in Figure 1.

Figure 1 Capraro's STEM interdisciplinary approaches



Problem-based learning is driven by challenging, open-ended problems with no one "right" answer. Problems/cases are context specific. Students work as self-directed, active investigators and problem-solvers in small collaborative groups (typically of about five students). A key problem is identified and a solution is agreed upon and implemented. Teachers adopt the role of facilitators of learning, guiding the learning process and promoting an environment of inquiry.

For this STEM project-based learning, students must be equipped with problem solving skills, and be able to find solutions for upcoming problems due to technological advancements; information is available, there is no place for memorization, and there is a need to develop and acquire new information and project outcomes based on observation and analysis. The importance of this approach is to provide the structure needed to formulate the best solution possible and further develop the learners' problem-solving skills.

Some of the benefits of the STEM project are 1) capturing students' interest by video clips, role playing, and so on; 2) Students should consider the big picture when creating or communicating their design; 3) Teachers provide guidance where needed by providing open-ended questions; 4) A key component of PBL is effective and contentious written and oral communication; and 5) Evaluation and development of metacognitive skills to develop and improve their project design.

Since 2007, the Knowledge and Human Development Authority (KHDA) in the UAE has started annual inspections of private schools using an inspection framework which has clear performance standards. Inspection reports are issued by the DSIB to the school leaders with specific recommendations. Schools are expected to address the recommendations by authoring an action plan to be submitted to the KHDA. This process calls for high expectations from private schools.

Recently, in 2014, HH Sheikh Mohammad Bin Rashid, UAE Vice President and ruler of Dubai, released the UAE Vision 2021 National Agenda which included seven indicators, one of which is the "First-Rate Education System." The first and fourth national key performance indicators of the "First-Rate Education System" focus on the nation's ranking and scores in TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment). In 2021, the targets for average TIMSS scores and average PISA scores were to be among the top 15 and 20 countries respectively. The KHDA proactively supported the private schools as of 2014 by setting individual specific targets for TIMSS 2015 and PISA 2015. Those targets were discussed in separate meetings with the school leaders. Many studies investigated the performance of students in the UAE in standardized tests and the shortfalls in mathematics and science education (UAE Vision, 2021). The annual inspection of private schools stresses the need to have accountable internal assessments that fairly evaluate students' performance. Schools' accountability is determined by the students' performance in standardized tests such as TIMSS and PISA. This demand brings out an urge for innovative initiatives to include STEM, project-based, and problem-based foci to raise the nation's interest in knowledge and education.

STEM Education and Professional Development

The theme of professional development as a mechanism to support STEM education continues throughout the literature. Many authors have called for STEM teachers to develop professionally in order to support and improve STEM education. The Research Experience for Teachers (RET) project, funded by the National Science Foundation, supports "the active involvement of K-12 teachers in STEM" areas including incorporating computer and information science in research projects to bring knowledge of engineering, computer science, and technological innovation into their classrooms. One of the goals of RET is the professional development of teachers to build collaborative partnerships that "help them translate their research experiences and new knowledge into classroom activities" (Pop et al., 2010, p. 127).

Two RET projects that have strong STEM teacher professional development components are "Enrichment Experiences in Engineering (E3) for Teachers Summer Research Program: An Examination of Mixed-Method Evaluation Findings on High School Teacher Implementation of Engineering Content in High School STEM Classrooms" from Texas A&M university, and from the University of Texas at Arlington: STEM High School Teaching Enhancement

Through Collaborative Engineering Research on Extreme Winds. Both of these projects have an emphasis on teachers having hands-on research experience where they develop inquiry-based engineering projects for their classrooms. Teachers learn about engineering career opportunities for students and develop an overall engineering career awareness. They are encouraged to participate in active sharing of the knowledge gained in the professional development experience. These programs and others like them support high quality professional development for teachers interested in STEM education with the overall goal of making them better teachers in the STEM disciplines (Arabian Business Consultants for Development, 2017; Eger, 2013).

The theme of collaboration as part of STEM teacher professional development is important in the assessment of STEM teachers in Professional Learning Communities (PLCs). This study which was completed in the fall of 2010 was a 2-year analysis funded by the National Science Foundation. There were five types of research included in the synthesis that were identified using variations of the search string "professional learning community." The research synthesis included empirical research studies published since 1995 in peer journals and dissertations, research-based articles in other journals, and conference proceedings (Eger, 2013).

The researchers found that participating in learning teams allows STEM teachers to successfully engage in discussion of the subjects that they teach. The authors found that teachers in STEM PLCs understood mathematics and science better and felt more prepared to teach their subjects. STEM PLCs cause instruction to change because teachers use more research-based methods for teaching, they pay more attention to students' reasoning and understanding, and they use more diverse modes of engaging students in problem solving (Daugherty, 2013). Another area of curriculum support for STEM education is the arts. In the article, The Prospect of an A in STEM Education, Michael Daugherty (2013) argues that art is essential to STEM education. Daugherty believes that by inserting an "A" for "Arts" in STEM education and making it “STEAM” education, educators can energize creativity and innovation in STEM education.

In his blog, Dr. Robert Root-Bernstein of Michigan State University (2011) pointed out that the arts do not make science or technology more aesthetic, rather they often make it possible. Instances where the arts directly led to the technology that Root-Bernstein cites include: “(a) electronic display screens consisting of red, green, and blue pixels which originated from the innovation and collaboration of post-impressionist painters like Seurat; (b) computer chips that are made using the classic art process of etching, silk screen painting and photolithography; and (c) in medicine where the stitches that permit a surgeon to correct an aneurysm or carry out a heart transplant were invented by American Nobel laureate Alexis Carrel, who took his knowledge of lace making into the operating room” (p. 34).

In a personal interview with Dr. Nealy Grandgenett, Professor and Haddix Community Chair of STEM Education at the University of Nebraska at Omaha, he stated that as part of the Nebraska Robotics Expo there is now a creative visual arts competition. This allows the participants to take part in the creative and aesthetic bits of the engineering design process. Daugherty (2013) argues that it may be in the interest of the STEM movement to consider additional learning goals specifically related to creativity as it pertains to innovation. Both Pink (2005), who sees the society changing from the Information Age to a “Conceptual Age” of inventiveness, innovation, and creativity, and Robert Root-Bernstein (2011), who states that successful innovators in science and technology are artistic, would agree. In summation, as society changes to a more conceptual age, we are encouraged and urged to strengthen creativity because successful innovators in science and technology tend to be artistic people (Daugherty, 2013; Root-Bernstein, 2011).

There are many student service and curricular areas that can support the successful integration of STEM education into the school setting. Counsellors and librarians play a vital role in students choosing STEM classes and providing them with the resources to be successful. Curricular areas including the arts can be vital support structures of students in STEM classes by allowing them to develop the creativity to solve the complex problems integrated STEM education presents (Daugherty, 2013).

In the UAE, the Ministry of Education has crafted a plan to achieve positive results in the TIMSS international assessments, ensuring alignment with the national agenda and the UAE 2021 Vision. It has been further emphasized to place students among the top 15 countries in the next TIMSS. The main goal is to reform education to become one of the best educational systems in the world, which will be measured by the country's performance in literacy, numeracy and scientific skills through TIMSS and PISA, as set out in the National Agenda Targets. According to Shaikh Mohammed bin Rashid, the national strategy of innovation focuses on knowledge integration in science, technology, engineering, mathematics, and other fields, all of which contribute towards strengthening the knowledge economy. STEM education has been introduced through the Abu Dhabi Educational Council (ADEC), where changes have been applied to the school curriculum to apply the STEM approach of teaching and learning. The UAE government is closely monitoring the progress of STEM implementation, encouraging schools through accreditation from the UAE’s Ministry of Education (MOE), Dubai UAE and Abu Dhabi Educational Council, and the Knowledge and Human Development Authority (KHDA).

Several programs, formal and non-formal, have been designed to encourage the implementation of STEM and to create social awareness. For instance, in 2013, UAE Abu Dhabi launched the TECHQUEST leadership program with the aim of shaping different attitudes towards STEM subjects, accompanied by school programs for children and a STEM teachers’ professional program that aims to equip teachers with new and effective teaching strategies (Jarrar, 2020). Also, the national efforts to develop STEM roles have potential, but they need to be strengthened to enable the country to achieve its industrial development plans and ambitions. The Triple Helix model supports the UAE's goals by developing the appropriate skills needed to establish a strong local workforce and improve economic growth by funding and managing R&D enterprises. The relationship between the Triple Helix components, (university-industry-government), STEM education, and their influence in student career choices is worth investigating because this model can continue to build human capacity, diversify the economy, and create a knowledge-based economy that is globally competitive as the UAE continues to move towards a post-oil era (Husain, 2022).

Trends and Issues in STEM Education in UAE

Several UAE STEM education trends are presented in this section, including identified Policy and Reform, Problem-Based Learning, Curriculum Integration, Career Aspirations, Gender Aspects, Professional Development, and Culturally-Embedded Resources, to resolve related issues. Table 2 presents a summary of major themes of several documents related to STEM education in the UAE, followed by supportive teacher interviews and discussion of the main trends.

Table 2 Document analysis themes of UAE STEM education

No	Source	Title	Aim	Themes
1.	MENA Herald (2019)	MBRSG organizes Sixth Policy Council Session on "Building an Inclusive UAE Society"	A policy that aims to support youth employment through STEM knowledge and skill-based work.	- Economic/education policy. - Career development.
2.	Europe, Middle East and Africa (EMEA) countries (2016)	Science, technology, engineering and mathematics education in EMEA advancing the agenda through multi-stakeholder partnerships	A comprehensive report on STEM education in EMEA, highlighting specific country and regional practices, and making recommendations.	- STEM education in EMEA. - Sustain collaboration and partnership. - Engaging girls in STEM programs. - Science fairs. - Partnerships
3.	The Economist Intelligence Unit (2018)	UAE Economic Vision: Women in Science, Technology and Engineering	An Economist Intelligence Unit report looks at the United Arab Emirates' strategy for becoming a knowledge-based economy, with particular attention paid to the role women will play in science, technology and engineering (STE) in the future.	- Need for research. - Empowering women in STEM education. - STEM education to solve Emirati unemployment https://vdocuments.mx/uae-economic-vision-women-in-science-technology-economic-vision-women-in.html?page=1

Table 2 (continued)

No	Source	Title	Aim	Themes
4.	Ignite School 2022	STEM - a culture of innovation	An inquiry-based teaching and learning model provides a platform for the development of creative STEM processes that weave together sustainable development, technology, analysis, logic, and innovation.	- STEM curriculum - Sustainable development - Teacher support - Makers' lab (student support) https://youtu.be/WvQsZAl4vtc
5.	United Arab Emirates (2015)	Persistence in the Abu Dhabi STEM Pipeline: Preparing Emirati Youth for Careers in the UAE Innovation Economy	A study, conducted by the MBRSG and the Emirates Foundation, investigated the "leaks" in the STEM pipeline in the Emirate of Abu Dhabi and found that students in both schools and universities showed a great deal of enthusiasm for STEM subjects and careers. Many viewed STEM preparation as an appropriate way to support the UAE's national agenda.	- Skilled and committed STEM workforce. - The fact that Emirati students are not filling the ranks of engineering, science, and technology jobs is of utmost importance. - Participation in STEM remains low. - STEM careers are still viewed as being time consuming, difficult and demanding. - Interest in math and science is closely related to students' enrolment in STEM fields.

Trend and issue 1: The increased demand for STEM in education has been implemented through national policy and reform to resolve the issue-lagging in preparing highly talented STEM workers in the past

The trend of the Policy and Reform relates to the increased demand for STEM in education due to government response in the UAE Vision 2021 (Nahil, 2016), as well as to meet the expectations of a diverse economy which is calling for more STEM-related professions and sectors in the UAE economy, especially in burgeoning sectors like science investigation, engineering, and renewable energy in the country. Makhmasi et al. (2012) pointed out that the recent STEM initiatives in the country like the Innovation Hub, which was launched by Al Bayt Mitwahid Association in collaboration with Google, have given a great deal of media coverage to STEM education in the UAE. The project was launched in Ras Al-Khaima emirate with a focus on introducing a STEM+ lab curriculum in schools. Makhmasi et al. (2012) pointed out that this is also considered to be the first official STEM initiative in the UAE.

With the concentrated efforts from the UAE government to strengthen and diversify its oil-based economy, the country has seen a surge in educational reforms which were highly concentrated on teaching science, technology, engineering, and mathematics subjects. The projects like the Smart Learning Programme (SLP) with a similar, albeit more ambitious, vision, have also been introduced in the recent past; however, the schools in the UAE require more practical knowledge of science and technology subjects, thereby making room for STEM educational reforms (Pennington, 2014). Compared to other Middle East countries, the UAE is not a leading contributor in technology and science developments given its economic and regional importance. While there have been continuous discussions over the nature, scale, and the extent to which there is a lack of science and technology developments, the majority of experiences have a common consensus that the problem is real and growing with the passage of time. Because of the decreasing trend of STEM in the

UAE, it is believed that students are mostly enrolling in degrees which are not fruitful for the development of the country and will ultimately affect the workforce available for businesses and industries. Hence, under the UAE Vision 2021, the educational system in the UAE needs to evolve and must provide highly talented STEM workers to reach its vision of becoming an innovative and self-sustaining economy. Through concerted efforts aimed at diversifying and strengthening the rising oil-based economy, the UAE has begun revamping its education system, particularly in STEM subjects (Makhmasi et al., 2012). However, Makhmasi et al. (2012) asserted that while STEM subjects are taught by teachers and schools with utmost vigor, interest, and high aspirations, it does not ensure that students will enroll and major in STEM fields or will become productive and innovative members of STEM professions. This is due to many challenges and barriers which might influence the choice of students to study for further education and for future career aspirations. Hence, it is important to cross this bridge by bringing more awareness of STEM in UAE society through an integrated STEM education framework which focuses on all stakeholders in the society (Makhmasi et al., 2012).

The Education Vision 2020 is a 5-year plan to improve teaching and training quality. It 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 (Burton & Warner 2017; UAE Vision 2030; Warner 2018). Furthermore, technology has improved across classrooms to develop the skills needed for the future careers of the students of the 21st century (Warner, 2018; UAE Vision, 2030). The UAE Vision (2021) was launched to establish a "first-aid education system" by His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice-President and Prime Minister of the UAE and Dubai Ruler. The most optimistic goal of the United Arab Emirates Vision 2021 is 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. Sheik Mohammed bin Rashid Al Maktoum announced eight pillars of progress.

Trend and issue 2: Project-based learning has been adopted as the main STEM instructional strategy to resolve the issue-traditional learning strategies are not suitable for preparing a STEM workforce

Project-Based Learning is another trend that is seen as a main STEM instructional strategy in the UAE government and private schools. This relates to the labor market demand and the quality of education that is required due to the nature of the jobs in the UAE. According to the 2021 UAE Vision, emphasis was placed on STEM, with increased financial contributions in graduate programs and research, growing STEM enrollment and expanding collaborations between education and professional growth in the country (UAE Vision, 2021). The need to implement advanced education initiatives, such as STEM, and creative educational strategies, for example, the PBL, is illustrated by a recent reform agenda in order to meet UAE education standards (UAE Vision, 2021). Proper implementation of a new program can help to quell, or at least minimize, the negative perceptions of a STEM program for educators. Research suggests that professional development can ease the transition into a new program (Sunyoung et al., 2015). One of the primary challenges is to successfully implement integrated STEM at various levels, be it at elementary, middle, and high school/K-12 levels or at the tertiary level. A master's study by Husam Jarrar (2020) aimed to investigate the impact of implementing the STEM PBL approach on elementary students' academic achievement in science compared to non-STEM PBL instruction in a private school in Sharjah, UAE. The study took a period of 6 weeks in the first term. It was hypothesized that there would be a statistically significant difference in the students' academic achievement between the students who were taught using the STEM PBL approach and those who did not. A pretest/posttest quasi-experiment was used in this study in order to investigate the impact of STEM PBL on students' achievement. The results showed that there was a statistical difference between the experimental and control groups, and from the pre- to posttest scores. The student achievement and the development of skills for the experimental and control groups in the posttest were found to be 7.38 and 6.07 respectively. Additionally, it was found that there was a statistical difference in the achievement of the students who were exposed to the STEM PBL in the experimental group compared to the control group where the independent t-test results between the scores means for both groups in the posttest showed that $t(110) = 4.142$ with a p value equal to $0.000 < 0.05$. The results of this study were consistent with previous studies. The findings indicated that STEM PBL enhances engagement collaboration, interest, understanding, awareness, and skills, which in turn enhances their productivity and achievement as the students clearly stated in the interviews (Lou et al., 2017).

Trend and issue 3: The curriculum integration has been pursued to resolve the issue—isolated (S, T, E, and M) concept of STEM education

The Curriculum Integration trend, as presented earlier in the chapter, is also derived from the analysis of a sample of teachers' interviews in the UAE. For the question, what does STEM education mean and what does a STEM curriculum look like? participants provided some definitions of a STEM curriculum and the need for true integration, such as "STEM is a curriculum based on teaching four specific subjects in a cohesive integrated way based on the real world." Participating teachers stated that STEM education characteristics incorporate problem and project based learning, integrating subjects meaningfully, applying higher order, critical thinking skills, and the use of technology and AI. "The integration between different disciplines, where students have the opportunity to be innovative and create solutions to their daily life problems." Other participants defined STEAM education as building projects with integration of the five fields. Appropriately, participating teachers stated appropriate understanding of STEM and STEAM education as it relates to the UAE context. These are echoed by recent research by Eltanahy et al. (2021) and Madani and Forawi (2019).

Additionally, responses alluded to the integration between disciplines that allow students to have the opportunity to be innovative and to create solutions to their daily life problems, as supported by earlier research, for example, Capraro et al. (2013) and Kelley and Knowles (2016). Responses regarding challenges of STEM education included lack of clear policies, modeling of instruction, resources, especially in the Arabic language, technology accessibility and training. Regarding questions of the PD opportunities provided to teachers and their STEM qualifications, responses varied; there are some professional development sessions in different topics, but not necessarily in STEM. Only a few teachers indicated that they had attended STEAM workshops run by experts with an emphasis on projects. It was also seen in the reviewed literature that the STEM and STEAM fields are more appropriately taught through projects such as STEAM yardstick activities and visiting sustainability pavilions at Dubai Expo 2020. Yet, such opportunities for STEM instruction were not common.

Trend and issue 4: Career aspirations have been explored to resolve the issue—students' ambiguous job preferences in STEM fields

As for the trend of Career Aspirations, the STEM career aspirations of Emirati youth were identified in one of our previous studies (Forawi, 2017). A large convenient nationwide sample of 5,320 students from grades 8, 10, and 12 were included in the study. The governmental school administrators, mainly principals who delegated communication to social workers or teachers who were responsible for facilitating activities such as this, agreed to have their school participate in the study and routed the questionnaire packets to be distributed to students in all or selected classes in grades, 8, 10, and 12. The Ministry of Education, delegated to the Educational Zones in the seven Emirates in the UAE, granted permission to collect data from selected governmental public schools, which are segregated into boys and girls schools. A successful career can be a source of self-esteem, fulfillment, and meaning in life. Career achievement often serves as a societal measure of an individual's quality of life and position in society.

Table 3 Top five rank-ordered preferred jobs as aspired to by Emirati youth

Number	Job	Frequency	Percentage
1	Engineer	662	15.90%
2	Police	603	14.50%
3	Doctor	493	11.80%
4	Pilot	351	8.40%
5	Army, Navy, Air Force	316	7.60%

Source: Forawi, 2017.

Table 3 indicates the future five top job preferences of all participating students for the 28 jobs stated in the Career and Educational Aspirations Questionnaire (CEAQ) instrument in descending order. The three top jobs included two of the top jobs, engineer and doctor (15.90% & 11.80%, respectively), which is similar to the results of previous studies. Engineering is a STEM job. This result is not unusual for students at this age where interest and actual ability to achieve such interest are not correlated. However, it is interesting to know that both boys and girls at the middle and secondary levels in the UAE are interested in becoming engineers, police officers, and doctors. In particular, the high interest in become a police officer was indicated by both boys and girls as it is seen as a lucrative job with many benefits. By applying the paired test, to know if there was a difference in students' responses about deciding for themselves or being influenced by others such as parents or other family members, it was found that there was a significant difference between the two ideas. Students preferred to depend on themselves when selecting their future jobs, but were open to advice from others.

Table 4 Means of Emirati youth opinion on deciding future jobs by gender

Gender	Advice from Others	Student's Own Idea
Male	3.33	3.31
Female	3.16	3.42

The majority of UAE boys and girls equally want to decide on their own future jobs and can accept advice from others. There was no significant difference regarding gender. As can be seen in Table 2, only girls showed a slight preference for deciding for themselves when it comes to their interest in future jobs. However, in contrast, the Afro-Caribbean students were found to shy away from science, and preferred to pursue degrees in the social sciences. Therefore, introducing the gender factor in this part, we found the result as shown in the table above which indicated equal opinions from boys and girls. Yet, girls showed more independence in deciding about their future careers. STEM education is therefore widely demanded.

Trend and issue 5: Culturally-embedded resources have been provided to resolve the issues—new technologies such as AI and their related materials are still in the developing stage in schools

The trend of Culturally-Embedded Resources calls for developing resources that are appropriate for students in the UAE context. Artificial intelligence (AI) has its presence in many aspects in the UAE, and education is no exception. Several schools, elementary, middle, and high, include elective subjects and programs that are related to AI. This is most seen as a need to develop related materials which are still in the developing stage, including simple robotics activities. One issue relates to developing STEM materials, software, equipment in the Arabic language with a cultural connection so students can relate to and be motivated to use and pursue the field. Several common companies and vendors in the country include: Atlab STEM Academy with the help of LEGO Education, PITSCO Education, PASCO Scientific, SAM Labs, and XYZ Printing that provide some STEM education resources, and programs for K-12 schools, in Dubai particularly. Some of these companies are attracted by the increased demand and the international exposure in the UAE, through government, academics, conferences, and so on.

Conclusion

There is a dearth of available in-depth literature and studies regarding STEM in the UAE. The current chapter can therefore be considered as a starting point that intends to determine the policy recommendation for the implementation of the integrated STEM Framework in UAE schools and thereby intends to address the gaps and the quality issues by understanding STEM advancement, mainly in areas such as stakeholders planning for interconnectedness between sectors and partnership with the community and other sectors, curriculum and level of integration, STEM job skills and competencies, teachers' preparation and professional development, delivery, and workforce demands. This chapter provides a comprehensive review including deep interpretation of the status of STEM education in the UAE. The main findings show that STEM education is reflected in the following cluster of themes: Needs and Reforms of STEM Education in the UAE, UAE STEM Education Practices and Challenges, and the Way Forward for STEM Education in the UAE, with some supporting subthemes: the historical account of STEM education, its theoretical and pedagogical frameworks, and STEM professional development that comprehensively provides a discourse on STEM education and its characteristics, and our related key study findings in the UAE. Yet, several challenges were noted: there is a need for clear STEM strategies, the development of curricula and programs, both at government and private schools as well as universities, based on real industry applications and sustainable resources that are in the Arabic language and are culturally embedded. Some encouragement for students to follow STEM pathways is evident in several research studies that were conducted with K-12 Emirati students. The nature of STEM education in terms of encouraging collaborative and creative work as well as developing students' autonomous learning was identified as the top of the list of effective learning. This was reflected in this chapter's cluster and subthemes presentation and discussion.

Recommendations to introduce STEM education into the curriculum and policy in the UAE may include competition and recognition awards. The award is a communications and outreach tool to encourage state education, health, and environment authorities, stakeholders, and school communities to consider matters of facilities, health, and environment comprehensively, strengthening the critical collaborations which ensure that all of our nation's schools are healthier, safer, and more sustainable. The recognition award, in the United States, honors public and private elementary, middle, and high schools, districts, and postsecondary institutions that are demonstrating a commitment to the three pillars of: (1) reducing environmental impact and costs, including waste, water, energy use, and alternative transportation; (2) improving the health and wellness of students and staff, including environmental health, nutrition, and fitness; and (3) providing effective sustainability education, including robust environmental education that engages STEM, civic skills, and green career pathways. Therefore, a country like the UAE should invest in such incentives and learning curve to encourage students to pursue STEM education majors and careers.

Policy makers, educators, and industries are working collaboratively and are influenced by the evolving global economy and the skills people need to participate in it. The emergence of STEM education decreases the gap between K-12 and the social and economic changes based on the number of characteristics that have implications for career development. A broad set of hard and soft skills are equally important and carefully embedded in the context of STEM approaches. In addition, the ability to learn continuously throughout life needs flexibility, creative thinking, conflict resolution, and the capacity for innovation. To some extent, STEM curricular designers are harnessing the power to center on the general skills for one’s career development within the wider global and local context.

Some of the challenges noted that there is low participation in STEM-related disciplines in the UAE of the tertiary education sector in the UAE in absolute terms and in comparison with other comparable nations. Stakeholders pointed out the lack of interest of students in STEM career paths, a lack of awareness of STEM, a lack of a working culture supporting STEM learning, and a conservative approach to timetables and curriculum delivery in UAE schools. While most of the findings of the career aspirations are not far from those findings indicated by international research studies, Emirati students seem to be influenced by other societal realities by indicating preferences for other jobs such as joining the police, the armed forces, and business, as many of their parents and others pursue such jobs. The desire for STEM-related jobs is still weak, which may be affected by limited awareness of such jobs, programs, and career counselling. Thus, the Emirati youth will continue to follow the steps of their fathers and close role models. STEM education provides a cooperative working environment for learners, enabling them to develop more expertise in sociocultural and communication issues. Integrating Science, Math, Engineering, and Technology disciplines in this study showed huge changes to the level of the student. By using the STEM PBL approach, students have shown improvement in their skills. The idea of curriculum integration enhanced student learning, as it helped them to gain further information that led to a deeper and stronger understanding of the subjects.

Finally, the UAE can introduce student advisors in schools to provide support and guidance in formal and informal STEM education programs and STEM careers. The STEM curriculum should be developed to align with such majors and career possibilities and to incorporate learning objectives to develop skills as in the project-based, design-based, and student-centered STEM education. In doing so, STEM education curricula and programs should be designed with industrial and business partnerships, sustainable funds, culturally sound materials, and environment-friendly goals.

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Status and Trends of STEM Education in the United States of America

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Abstract

The acronym STEM is a term used to group together the academic disciplines of Science, Technology, Engineering, and Mathematics and their associated content, practices, and applications (ITEEA, 2020). This chapter looks at the current status of STEM jobs in the United States of America (the USA or the U.S.) and discusses why STEM Education is important. The chapter's primary focus is on public STEM education at the kindergarten through secondary education (K-12) level, but there are some references to STEM education in higher education. The USA has no national curriculum in STEM education, or the other subjects taught in public schools, but it does have national student assessments that help shape the status of STEM education. Some of the best universities are in the U.S.; however, at the K-12 level, students do not perform that well in the STEM areas when compared with their peers from around the world. The chapter presents findings from these assessments. Also, presented is a snapshot of STEM careers, including those requiring college and those not requiring college. Finally, the article presents five questions that address the issues that the author believes must be addressed to move K-12 STEM forward in the U.S. and a discussion related to trends in STEM education. If the U.S. wants to continue to compete in the world, its K-12 students must receive a solid STEM education that helps to improve their performance in the STEM areas and introduces them to STEM career options.

Keywords: STEM, K-12 STEM education in the USA, assessment of STEM subject areas, STEM careers, issues in K-12 STEM

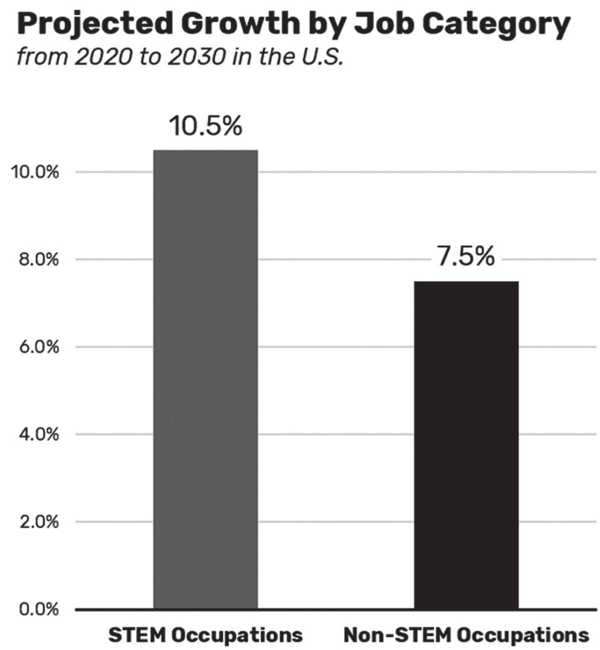
In the United States of America (USA or U.S.) the acronym STEM is a term used to group together the academic disciplines of Science, Technology, Engineering, and Mathematics and their associated content, practices, and applications (ITEEA, 2020). In the U.S., the use of the term STEAM has been gaining some momentum (Institute for Arts Integration and STEAM, n.d.), where the "A" in STEAM typically refers to the Arts (although the author has seen the "A" in STEAM refer to Agriculture).

Art is about creative expression and adding art (and design) elements to STEM helps promote creativity and innovation. However, this author believes that art is inherent in the teaching of STEM, especially in the areas of technology and engineering. As engineers create technology, they must also consider the design aspects. Therefore, this article, from an American perspective, focuses on STEM and STEM education.

Introduction

STEM education helps prepare students to pursue careers in STEM. In the U.S., there is a shortage of STEM workers (i.e., those who graduate with a higher education degree in a STEM-related field). Between 2020 and 2030, U.S. jobs in STEM are expected to grow 10.5%, to more than 11 million. Figure 1 shows that the U.S. Bureau of Labor Statistics (2021) which measures labor market activity, predicts that STEM occupations are projected to grow 1.4 times faster than non-STEM occupations (10.5% STEM vs. 7.5% non-STEM) (Angier, 2022).

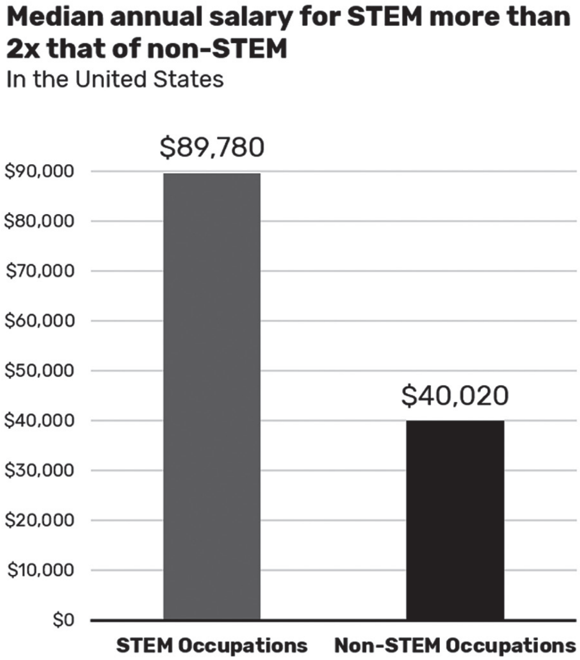
Figure 1 U.S. Bureau of Labor statistics prediction that STEM occupations are projected to grow 1.4 times faster than non-STEM occupations



Source: U.S. Bureau of Labor Statistics, 2021.

In addition to the need for STEM Occupations, the wages for STEM higher education graduates are generally higher than those for non-STEM occupations. Figure 2 shows the annual median salary for STEM degree graduates is two times higher (i.e., $89,780, vs. $40,0200 than those who graduate in a non-STEM occupation (U.S. Bureau of Labor Statistics, 2021).

Figure 2 U.S. Bureau of Labor statistics predictions of STEM salaries



Source: U.S. Bureau of Labor Statistics, 2021.

The U.S. Educational System

In the U.S., kindergarten through 12th grade (K-12) schooling is primarily achieved through public education. Although there are some private schools (e.g., that include a secular perspective), they tend to be smaller than the public schools, and often expensive. There is also an option for parents to "home school" their children or send them to a "charter school." A charter school is a school that receives government funding but operates independently of the established state school system in which it is located. According to the National Center for Education Statistics (NCES, n.d.) in the fall of 2020, there were 49.4 million public school students enrolled in prekindergarten through grade 12 and they also noted in 2019–20, about 4.7 million students attended private schools.

Public education is free and is supported through local taxes, and state and federal funding. Public education is compulsory and the age when students can drop out varies by state; the range is typically between 14-18 years of age. According to the National Center for Education Statistics (2022), in 2019, there were 2.0 million status dropouts between the ages of 16 and 24, and the overall status dropout rate was 5.1%. Status dropouts represent the percentage of 16- to 24-year-olds who are not enrolled in school and have not earned a high school credential. The overall makeup of the U.S. educational system is shown in Figure 3 (Kaull, 2016).

In the U.S., primary or elementary school public education classrooms are typically self-contained, meaning they are taught by one teacher. After elementary school, students attend secondary education programs where they rotate through classes. In the U.S., secondary education typically includes a middle/junior high school experience and a high school experience. The courses required of students in middle/junior and high school vary by state, but most are required to complete the "core" areas of English, science, social studies, and math, and to participate in physical education or health courses. In addition to the core courses, there are many elective courses students can choose from, and these elective courses will typically vary by region and state. Examples of elective courses include those related to foreign languages, visual arts, career and technical education, computer science, journalism and publishing, choir and band, business education, family and consumer sciences, agriculture education, and driver’s education.

Figure 3 The American school system

age	school		grade	student	Examinations / degrees
3	Nursery School				
4					
5	Kindergarten				
6	Elementary School or Primary School		first		
7			second		
8			third		
9			fourth		
10			fifth		
11	Middle, school or Junior High school		sixth		
12		Intermediate school	seventh		
13			eighth	student	
14		High school	ninth	Freshman	Examinations / degrees
15	Senior High school		tenth	Sophomore	
16			eleventh	Junior	
17			twelfth	Senior	High school Diploma
18	Community College		1	Undergraduate	
19			2		Associate in Arts/Science
20	University or College		3		
21			4		Bachelor of Arts/Science
22				(Post)Graduate	Master of Arts/Science
...			...		Doctor of Philosophy

In the U.S., there are high schools that focus on STEM education. Each year the publication known as the *U.S. News & World Report* provides a list of the best high schools for STEM. Their rankings methodology is based on the key principle that students at these schools must participate in a robust curriculum of college-level math and science courses and earn qualifying scores on official exams. The rankings do not look at technology and engineering literacy. In 2022, the *U.S. News & World Report* looked at 1,000 top-ranked high schools to identify the best in math and science education (Morse & Brooks, 2022). The list of top-performing high schools in the U.S. in STEM can be reviewed here: https://www.usnews.com/education/best-high-schools/national-rankings/stem

While in high school, students (typically in grades 11 or 12) can enroll in "competency-based" career and technical education (CTE) programs and receive specialized training, and often this is in a STEM-related field. Enrolling in CTE (formerly known as vocational education in the U.S.) programs is a “low -cost” option (when compared to university tuition) and a popular option for many students to become certified in a CTE area. As the U.S. Department of Education (2019) notes, “in 2017, CTE concentrations in STEM and STEM-related (Health Science; Agriculture, Food, and Natural Resources; and Information Technology) career clusters represented 35 percent of all CTE concentrations in high school” (para. 7). In addition, many CTE programs offer adult programs. After high school, students can enroll in a community college program that offers an associate degree in a STEM-related field, or pursue a university STEM-related degree.

STEM Education as a National Agenda Item

In the U.S., STEM education is a national agenda item. It is a teaching and learning approach that supports purposely showing the connections of each of the STEM disciplines, and introducing students to careers in STEM is not a single subject or a curriculum, it is a way of organizing and delivering instruction (NSTA, 2020). The U.S. Department of Education (n.d.) notes the importance of STEM and provides of variety of resources related to STEM. These resources include funding opportunities and relevant and timely information about STEM. They state the importance of STEM in the following quote:

> In an ever-changing, increasingly complex world, it's more important than ever that our nation's youth are prepared to bring knowledge and skills to solve problems, make sense of information, and know how to gather and evaluate evidence to make decisions. These are the kinds of skills that students develop in science, technology, engineering, and math—disciplines collectively known as STEM. If we want a nation where our future leaders, neighbors, and workers have the ability to understand and solve some of the complex challenges of today and tomorrow, and to meet the demands of the dynamic and evolving workforce, building students' skills, content knowledge, and fluency in STEM fields is essential (para. 1).

STEM education became a priority for the USA when The White House (2018) released *The STEM Education Strategic Plan, Charting a Course for Success: America's Strategy for STEM Education*. This plan set out a federal strategy for a future where all Americans will have lifelong access to high-quality STEM education and where the U.S. will be the global leader in STEM literacy, innovation, and employment.

A diverse talent pool of Americans with strong STEM knowledge and skills prepared for the jobs of the future is essential to maintaining the national innovation base that supports key sectors of the economy, including agriculture, energy, healthcare, information and communications technologies, manufacturing, transportation, and defense, along with “emerging areas like artificial intelligence and quantum information science” (The White House, 2018, p. 6). The plan focused on three broad goals for STEM education, as follows:

1. Building strong foundations for STEM literacy by ensuring that every American has the opportunity to master basic STEM concepts, including computational thinking, and to become digitally literate.
2. Increasing diversity, equity, and inclusion in STEM and providing all Americans with lifelong access to high-quality STEM education, especially those historically underserved and underrepresented in STEM fields and employment.
3. Preparing the STEM workforce for the future including both college-educated STEM practitioners and those working in skilled trades that do not require a four-year degree.

The author believes the above goals can be easily modified and are good for all nations who want to improve STEM education in their country. A modification of these goals would show a need to (1) build strong foundations for STEM literacy, (2) increase diversity, equity, and inclusion in STEM, and (3) prepare a STEM workforce for the future.

In addition, there are many benefits associated with STEM education. The author believes that students who learn how the components of STEM are connected learn to more easily see the "big picture" (i.e., an understanding of how all the components are connected). The big picture is that ah-ha moment when students say things like "now I understand" or "so that is how this works."

The National Inventors Hall of Fame (n.d.) discusses the idea that STEM-based education teaches children more than science and mathematics concepts; it helps them develop real-world learning applications and needed 21st century skills (e.g., technological literacy, problem-solving, critical thinking, collaboration, decision making, and leadership). The author fully supports the thinking of Lynch (2019, paras. 2-9) who notes the following benefits of STEM Education:

- It fosters ingenuity and creativity. Without ingenuity and creativity, the recent developments in artificial intelligence or digital learning would not be possible. These technologies were created by people who learned that if the human mind can conceive it, the human mind can achieve it.
- It builds resilience. Students learn in a safe environment that allows them to fail and try again.
- It encourages experimentation. Without a little risk-taking and experimentation, many of the technological advancements that have occurred in the last couple of decades would not have been possible. STEM encourages students to "try it and see what happens."
- It encourages teamwork. STEM education encourages students to work together (collaborate) in teams to find solutions to problems, record data, write reports, give presentations, etc.
- It encourages knowledge application. In STEM education, students are taught skills (e.g., problem-solving) that they can use in the real world, and this motivates them to learn.
- It encourages the use of technology. STEM learning teaches kids about

the power of technology (e.g., computers, 3-D printers, data collection devices, etc.) and to embrace it instead of being hesitant or fearful.

- It teaches problem-solving. STEM education teaches students how to solve problems by using their critical thinking skills (e.g., by brainstorming many solutions to a given problem).
- It encourages adaptation. STEM education teaches students to adapt the concepts and practices they learn to new problems, issues, or challenges that they face.

Before discussing the status of STEM education in the U.S., it is important to note that the COVID-19 pandemic substantially impacted the global economy. In the U.S., the new normal resulted in a lot of education moving to an online model where teachers faced challenges engaging students in the content to be learned. In the area of STEM education, this is even more challenging for many teachers as STEM activities often require students to work in groups to complete real-world problem-solving activities.

Li and Lalani (2020) discuss how the COVID-19 pandemic has changed education forever in the world. Key takeaway points from their discussion note that:

- COVID-19 has resulted in schools shut all across the world. Globally, over 1.2 billion children are out of the classroom.
- As a result, education has changed dramatically, with the distinctive rise of e-learning, whereby teaching is undertaken remotely and on digital platforms.
- Research suggests that online learning has been shown to increase retention of information, and take less time, meaning the changes coronavirus have caused might be here to stay.

In the U.S., the pandemic made worse pre-existing socioeconomic differences, such as a lack of access to computers and broadband at home for low-income and some minority students (Beaunoyer et al., 2020). The unemployment rate of STEM workers was lower than that of non-STEM workers, but women in STEM experienced higher unemployment than their male counterparts. Lack of access to technology for online learning was reported at higher rates for some minority groups (Okrent & Burke, 2021).

The Status of STEM Education in the U.S.

Before looking at the status of STEM education in the U.S., it is helpful to look at how the U.S. competes in the world economy. Unfortunately, the U.S. is not at the top of the ranking. The International Institute for Management Development (IMD) publishes a *World Competitiveness Yearbook (WCY)* which is a comprehensive annual report and worldwide reference point on the competitiveness of countries in the world. The WCY provides benchmarking and trends, as well as statistics and survey data based on extensive research. In its most recent report of 2021, it showed the USA had a ranking of number 10 when compared to other economies in the world. The top 10 performing economies from this list are shown below (IMD, 2021):

1. Switzerland
2. Sweden
3. Denmark
4. Netherlands
5. Singapore
6. Norway
7. Hong Kong SAR
8. Taiwan
9. UAE
10. USA

The Components of STEM

Those involved in teaching some aspect of STEM, and this could include practicing teachers or those involved in teacher preparation, must have a good understanding of the basic concepts associated with each of the disciplines. Since math and science are core subjects (i.e., required of all students), most have a good understanding of what is involved in these subject areas. The areas of technology and engineering are less understood, as many only associate technologies with educational (instructional) technology or information and communication technology (ICT). Both these technologies are important, as educational technology (e.g., a Smart Boards or LCD projectors) is used to enhance the learning environment, and ICT covers a broad spectrum of communications (e.g., the internet, wireless networks, cell phones, computers, and software) and other media applications and services enabling users to access, retrieve, store, transmit, and manipulate information in a digital form (Food and Agriculture Organization, n.d.). But in STEM, technology is so much more.

Technology is about modifying the natural world to meet human needs and wants (e.g., the smartphone or iPad has been developed to keep us informed and entertained). Technology has been around for a long time (e.g., the ax or wheel) and it has both positive and negative effects on society (e.g., plastic bags make it easy to carry our food, but they do not deteriorate easily and contribute to a growing problem of polluting the streets and landfills). Engineering refers to both a profession (e.g., Civil Engineer or Electrical Engineer) and a process of doing things. Engineers create technology. In STEM, engineering is used to create technology.

In 2020, the International Technology and Engineering Educators Association (ITEEA) released the Standards for Technological and Engineering Literacy – STEL that define the role of Technology and Engineering in STEM Education. To effectively teach STEM, teachers need a good understanding of its components. The STEL does an excellent job of this, describing the components of STEM as follows (ITEEA, 2020, p. 21):

- Science involves the investigation and understanding of the natural world.
- Technology is the modification of the natural environment through human-designed products, systems, and processes to satisfy needs and wants.
- Engineering is the use of scientific principles and mathematical reasoning to optimize technologies in order to meet needs that have been defined by criteria under constraints.
- Mathematics enables communication and critical analysis and how we make sense of the human and natural world using numbers and computational reasoning.

STEM Teacher Training

In the U.S., most teacher education programs are still subject specific. For example, a science education pre-service training program will focus on preparing students to teach science and its related content and practices. Teaching STEM requires that students have a good understanding of all the STEM disciplines, and their related content and practices. Unfortunately, this rarely happens and will depend on how much the pre-service program values the teaching of STEM and the backgrounds of its instructors.

In many instances, the teaching of STEM requires a "new mindset" for pre-service (and practicing) teachers. FutureLearn (2021) notes that teaching STEM subjects can require non-traditional approaches to learning and they provide good advice on teaching STEM. The author believes it is necessary for pre-service (and practicing) teachers involved in the teaching of STEM to heed this advice. This advice includes:

- Knowing the STEM subjects.
- Knowing the high demand of career opportunities in the STEM professions.
- Knowing that STEM education is about bridging the gap between the classroom and real life.
- Using Project-Based/Problem-Based Learning (PBL) when teaching STEM.
- Using inquiry-based learning that encourages students to ask a lot of questions.
- Knowing that STEM lessons need to be hands-on, mimic real-life scenarios, and should integrate math and science seamlessly into the problem or project.
- Incorporating the Engineering Design Process into lessons.
- Using formative assessment to assess students.

They further note that when STEM is effectively taught to students, some of the skills students are likely to develop include:

- Critical thinking
- Independent learning
- Great communication and collaboration
- Digital literacy
- Problem-solving
- Creativity
- Self-reflection

In the U.S., there is a current teacher shortage (García & Weiss, 2019; Maxouris & Zdanowicz, 2022). In some instances, teachers are asked to teach in areas where they have not been formally trained, and in some states, individuals are being hired to teach without having received any formal training in teaching (STEM Smart Brief, n.d.b; Strauss, 2017).

There are many factors causing the teacher shortage. Barnes (2022) does a good job of noting these factors that relate to teacher burnout, the COVID-19 pandemic, and the decline of undergraduate teacher education programs. For each of these factors, he notes:

- Burnout continues to be a driving force behind a nationwide teacher exodus that has left the industry with around a half a million fewer teachers.
- COVID-19 has only exacerbated a nationwide shortage that is decades in the making;
- The current staffing crisis is compounded by a massive decline in undergraduate degrees in teacher education programs, low pay, expanded opportunities for women and a lack of teaching degrees in STEM fields.

STEM Education

The components of STEM are brought to life in STEM education. STEM education is a teaching and learning approach where instructors show connections to two or more (*preferably all*) of the concepts in each of the STEM disciplines. It is about problem-solving, often focusing on students solving real-world problems. It is teaching students about STEM careers and promotes hands-on learning and creativity. It is about moving away from traditional teaching (i.e., where the teacher delivers all the information) to a teaching and learning approach where teachers serve as mentors to help students learn.

STEM education has many definitions and interpretations and there is no one correct definition. The author defines it as a "teaching and learning approach where science, technology, engineering, and mathematics (STEM) content, concepts, and practices are purposely integrated." The ITEEA views STEM as an integrative approach (ITEEA, n.d.). An integrative approach combines the disciplines, and they operationally define integrative STEM Education as

> the application of technological/engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels" (Wells & Ernst, 2012/2015). (as adapted from Wells/Sanders program documents 2006-10) (ITEEA, n.d., para.1).

The Southeast Asian Ministers of Education Organization (SEAMEO) and their STEM-Ed Center provide a very clear and concise definition of STEM education as

> a teaching and learning approach, which emphasizes the connections among – or the integration of – knowledge and skills in science, technology, engineering, and mathematics (STEM) to address problems facing our communities as well as larger global issues that require a skilled workforce and knowledgeable citizens who can apply these skills and knowledge to develop solutions (SEAMEO STEM-ED, n.d., para. 1).

Important practices taught in STEM Education are science investigation and engineering design. Science investigation refers to an organized plan and process for asking questions and testing possible answers related to science. In science investigation (e.g., experimentation or data collection) students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. Engineering design is an iterative problem-solving approach engineers often use to solve real-world problems. There is no one correct model they use, but most approaches involve clearly identifying and researching the problem (and this may include gaining an empathic understanding of the problem), proposing possible solutions, building and testing a model or prototype related to the solution, and presenting a solution to the problem.

Status of K-12 STEM Education

The current status of kindergarten through secondary (K-12) STEM education in the U.S. is a little difficult to determine. One major problem is that there is NO national curriculum for STEM education. Each of the 50 states has its own Department of Education and they can implement STEM education as best they see fit. However, as previously noted, STEM education is very important in the U.S. and is considered a national agenda item. To examine the status of STEM education, it is helpful to look at the national reports and studies to see how the U.S. is competing in STEM education with the rest of the world.

Some of the top universities in the world are in the USA (Carlton, 2022). One therefore would also believe that the USA is a leader in primary through secondary STEM education (P-12). Unfortunately, this is not the case, and the latest report from the National Science Board (NSB) finds that the performance of U.S. students in STEM education continues to lag behind that of students from other countries (Gillespie, 2021).

A good indicator of the status of STEM education in the U.S. can be found in the *Elementary and Secondary STEM Education* report (Rotermund & Burke, 2021). This report notes that a mixed picture is presented on the status and progress of elementary and secondary STEM education in the U.S.; the following key points were noted:

- Internationally, the U.S. ranks higher in science (7th of 37 Organization for Economic Co-operation and Development [OECD] countries) and computer information literacy (5th of 14 participating education systems) than it does in mathematics literacy (25th of 37 OECD countries). Students' achievement in mathematics has been essentially stagnant for more than a decade after showing steady improvement in the prior two decades.

- Average scores for U.S. fourth and eighth graders on a national assessment of mathematics improved from 1990 to 2007, but there was no overall measurable improvement in mathematics scores from 2007 to 2019.
- Differences persist in U.S. science, technology, engineering, and mathematics (STEM) achievement scores by socioeconomic status (SES) and race or ethnicity.
- Differences in U.S. STEM achievement scores by sex are smaller than those by SES or race or ethnicity but are present; male students slightly outscored female students on some national assessments, although female students substantially outscored male students on a computer information literacy exam.
- Less experienced STEM teachers (as measured by years of teaching) are more prevalent in schools with high-minority enrollment or high-poverty enrollment.

The U.S. could do better in preparing K-12 students in STEM education. Collectively, the findings in this report suggest that the U.S. has yet to achieve the goal of ensuring equal educational opportunities in STEM for all students regardless of socioeconomic and demographic background (Rotermund & Burke, 2021).

A further review of *The State of U.S. Science and Engineering 2022* (Burke, et al., 2022) provides another glimpse of the status of STEM in the U.S., especially in higher education. For example, some key indicators note:

- The U.S. science, technology, engineering, and mathematics (STEM) labor force represents 23% of the total U.S. labor force, involves workers at all educational levels, and includes higher proportions of men, Whites, Asians, and foreign-born workers than the proportions of these groups in the U.S. population.
- Blacks and Hispanics are underrepresented among students earning sci-

ence and engineering degrees and among STEM workers with at least a bachelor's degree. However, their share of STEM workers without a bachelor's degree is similar to their share in the U.S. workforce.

- Disparities in K–12 STEM education and student performance across demographic and socioeconomic categories and geographic regions are challenges to the U.S. STEM education system, as is the affordability of higher education.
- The U.S. awards the most science and engineering doctorates worldwide. Among science and engineering doctorate students in the U.S., a large proportion are international and over half of the doctorate degrees in the fields of economics, computer sciences, engineering, and mathematics and statistics are awarded to international students.

The State of U.S. Science and Engineering report further discusses the STEM workforce. It notes that it is large, consisting of 16 million workers with at least a bachelor's degree and nearly 20 million workers in the skilled technical workforce (STW) who do not have a bachelor's degree and that there are opportunities to increase the STEM workforce with domestic talent, particularly at the bachelor's degree level or higher. Finally, the report notes that enabling all Americans to receive high-quality STEM education and to pursue any science and engineering field of study or career are critical components of sustaining and growing the U.S. STEM labor force (Burke et al., 2022).

In discussing the status of STEM education, it is also important to look at the funding of public education in the U.S., especially at the K-12 level. Funding for public education comes from local cities, counties, state budgets, and the federal government. The U.S. is not a leader in funding public education. As Hanson (2022) notes, "In the U.S., education spending falls short of benchmarks set by international organizations such as UNESCO, of which the U.S. is a member. The nation puts 11.6% of public funding toward education, well below the international standard of 15.00%" (p. 1). In her report on *U.S. and World Education Spending* (2022), a few of the following key points note:

- K-12 public schools spend $14,455 per pupil -- expenditures are equivalent to 3.53% of taxpayer income.
- The difference between spending and funding is $1.50 billion or $37 per pupil.
- In postsecondary education, the U.S. spends more than any other country at $33,180 per full-time student.
- Schools in the U.S. spend an average of $12,624 per pupil, which is the fifth-highest amount per pupil among the 37 other developed nations in the Organization for Economic Co-operation and Development (OECD).
- In terms of a percentage of its gross domestic product (GDP), the United States ranks 12th among OECD members in spending on elementary education.
- The United States does not meet UNESCO's benchmark of a 15.00% share of total public expenditure on education.

When trying to determine the status of STEM education in the U.S., it is important to examine all the evidence available. In the U.S., national-level data on student achievement comes primarily from two sources: the National Assessment of Educational Progress (NAEP), also known as the *Nation's Report Card*, and the U.S.'s participation and collaboration in international assessments, such as the *Trends in International Mathematics and Science Study* (TIMSS) and the *Program for International Student Assessment* (PISA).

The *Nation's Report Card* (n.d.) looks at achievement in STEM-related subjects in the U.S. The report focuses on achievement in grades 4, 8, and 12 and is administered by the National Assessment of Educational Progress (NAEP). NAEP assessments measure students' knowledge and skills in various subject areas and report achievement levels. Results are reported as percentages of students performing at or above three achievement levels (i.e., NAEP Basic, NAEP Proficient, and NAEP Advanced). Students performing at or above the NAEP Proficient level on NAEP assessments demonstrate solid academic performance and competency over challenging subject matter.

The most recent data is from 2019 for science and math, and 2018 for technology and engineering. In 2018, the Technology and Engineering Literacy (TEL) assessment was only given at the 8^{th}-grade level. Therefore, the following represents highlights for the 8th-grade from the 2018 and 2019 assessments (The Nation's Report Card, n.d.).

- In 2019, only 35% of eighth-grade students performed at or above the NAEP Proficient level on the science assessment, which was not significantly different from 2015 but was four percentage points higher than in 2009. Furthermore, in 2019 only 2% of eighth-graders performed at the NAEP Advanced level, which was not significantly different from 2015 but was higher than in 2009.
- In 2019, average mathematics scores for the nation were one point lower at grade eight than in 2017. No significant change in the percentages of eighth-grade students performing at or above NAEP Proficient compared to 2017. The NAEP eighth-grade mathematics proficient level was 34%.
- In 2018, about 46% of eighth-grade students performed at or above the NAEP Proficient level on the technology and engineering literacy, which was significantly higher than the 43% of students in 2014, the previous assessment year.

If the U.S. is to globally compete in STEM, K-12 students must be better prepared in the STEM areas. A review of the NAEP achievement levels in the STEM subject areas shows a need for improvement, especially in the math and science areas where only about a third of the eight-grade students were at the NAEP proficient level. However, the technology and engineering literacy assessment showed promising results as almost half of the students who took the assessment were at the proficient level. It is interesting to note that in 2018 females scored higher than males on NAEP's TEL. This aligns with one of the conclusions in ITEEA's *Learn Better by Doing Study* (Moye et al., 2018) that technology and engineering activities promote female interest and participation in STEM education and occupations.

The TIMSS and PISA are two international comparative studies in educational achievement. The TIMSS is the U.S. source for internationally comparative information on mathematics and science achievement in the primary and middle grades. The PISA is the U.S. source for internationally comparative information on the mathematical and scientific literacy of students in the upper grades at an age that, for most countries, is near the end of compulsory schooling (Scott, n.d.).

The most recent PISA assessments from 2018 are shown in Figure 4. The PISA is a worldwide study by OECD in nearly 80 nations of 15-year-old students' scholastic performance in mathematics, science, and reading. A quick review shows that the U.S. is not the leader. In fact, the U.S. achieved a ranking of 25 when compared to the rest of the world (FactsMap, n.d.). There is a need to improve these scores if the U.S. wants to continue to stay competitive in STEM in the world.

The most recent TIMSS assessments in mathematics and science are from 2019 and are shown in Figures 5 and 6. A quick review shows that the U.S. is not the leader in math or science. In fact, the U.S. achieved a ranking of 15 in math and a ranking of 11 when compared to the rest of the world (Hatch, 2020). There is also a need to improve these scores if the U.S. wants to continue to stay competitive in STEM in the world.

In reviewing the data from the most recent TIMSS and PISA assessments, it shows that students in the U.S. continue to lag behind their peers in East Asia and Europe in reading, math, and science. The data also shows widening disparities between high and low performing students in the U.S. which adds to a growing body of evidence showing worsening inequity in public schools.

Again, the results of these international exams seem to suggest that U.S. schools are not doing enough to prepare young people for the competitive global economy (Balingit & Van Dam, 2019).

Figure 4 PISA 2018 worldwide rankings showing the average scores for math, science, and reading

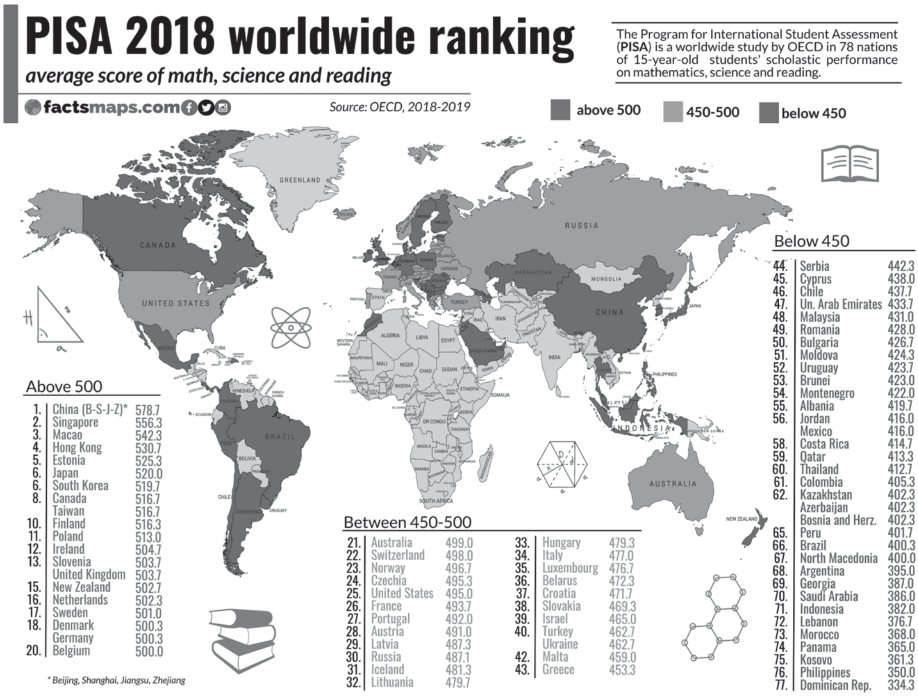


Figure 5 TIMSS worldwide math rankings

Timss maths rankings - 10 year olds

COUNTRY	Rank (2015)	2019	2015
Singapore	1 (1)	625	618
Hong Kong	2 (2)	602	615
South Korea	3 (3)	600	608
Taiwan	4 (4)	599	597
Japan	5 (5)	593	593
Russia	6 (7)	567	564
Northern Ireland	7 (6)	566	570
England	8 (10)	556	546
Ireland	9 (9)	548	547
Latvia	10 (-)	546	-
Norway	11 (8)	543	549
Lithuania	12 (16)	542	535
Austria	13 (-)	539	-
Netherlands	14 (19)	538	530
United States	15 (14)	535	539

Figure 6 TIMSS worldwide science rankings

Timss science rankings - 14 year olds

COUNTRY	Rank (2015)	2019	2015
Singapore	1 (1)	608	597
Taiwan	2 (3)	574	569
Japan	3 (2)	570	571
South Korea	4 (4)	561	556
Russia	5 (7)	543	544
Finland	5 (-)	543	-
Lithuania	7 (15)	534	519
Hungary	8 (12)	530	527
Australia	9 (17)	528	512
Ireland	10 (10)	523	530
United States	11(10)	522	530
Sweden	12 (14)	521	522
Portugal	13 (-)	519	-
England	14 (8)	517	537
Turkey	15 (21)	515	493

Trends and Issues in STEM Education

Before looking at the trends and issues in STEM education, it is helpful to review the current trends and issues of education in general in the U.S. Perhaps the biggest issue in the U.S. is the current teacher shortage. Maxouris and Zdanowicz (2022) discuss that teachers are leaving the profession and few people want to join the field. They further discuss how teacher education programs are closing and that the educator profession is in crisis.

Byers (2022) shared what he believes are the emerging trends in education for 2022-2025 and the author agrees with these trends. Shown below are the seven top trends he identified, and a brief comment related to the trend. How these trends will affect STEM education in the U.S. is unknown, but the author believes there will be impacts, especially in trends related to student learning. However, the verdict is still out on how trends in online learning will affect K-12 STEM education which often requires hands-on learning and groups working together to solve real-world problems.

1. Neuroeducation Makes Inroads. The emerging field of educational neuroscience is shedding light on what works best when it comes to learning new concepts and skills.
2. Microlearning Gains Traction. Microlearning is a form of spaced repetition learning, in which lessons are broken up into bite-sized chunks and repeated over time.
3. Online Learning Gains Ground. The three major benefits of online learning compared to offline are: cost, convenience, and scale. The classroom of the 21st century may be 100% online (via virtual reality or augmented reality).
4. Instructors with Star Power. Online classes are growing, and famous people are involved in the teaching or training of the content.
5. Independent Entrepreneurs Launch More Online Courses. A number of new players in the "learning management system" (LMS) space have made launching a course a lot easier.
6. Niche Education Platforms Take Off. Advanced courses are being developed in professional fields (e.g., cybersecurity).
7. New Startups Offer More Homeschooling Options. About 3.4% of school-aged children in the U.S. are homeschooled each year and a variety of education startups have entered the homeschooling space.

Trends in STEM Education

The Covid-19 pandemic has changed how we teach, and the teaching of STEM related courses at all levels of education has been impacted. The author agrees with Metalios (2021) who identified the top three trends that have emerged in STEM education during the pandemic that can be expected to be continued. These trends include:

Trend 1. STEM educators will use more eLearning video services even after the pandemic is over
Trend 2. STEM educators will incorporate social media into their classroom
Trend 3. STEM educators will use more artificial intelligence (AI) in the classroom

The pandemic has changed how teachers teach, and many teachers will continue to use online services (e.g., YouTube) to provide students with up-to-date information on STEM-related topics. Also, more teachers will use social media (e.g., Twitter) to share STEM information, and AI can be used to automate administrative tasks for teachers (Metalios, 2021).

In addition to the above trends, the author believes another trend in STEM education (i.e., trend #4) will be to make it more important at all levels of education.

Trend 4. Increase the importance of STEM education

The author agrees with Athanasia and Cota (2022) that the U.S. needs to reinvigorate its STEM education system if it is to compete successfully in the 21st century. Emerging technologies and maintaining a strong national security requires solid capabilities in the STEM fields. STEM education must become a priority at all levels of education. Students must be given the resources and experiences needed to pursue a career in STEM if they so desire. Furthermore, strong research must show the importance of STEM education. Fortunately, as Li et al. (2020) note, research in STEM education is increasing in importance.

Trend 5. Increased teacher training in STEM education

STEM education is important. It requires quality teachers who can effectively show students how the disciplines are connected and teach them about all the STEM career opportunities. Teacher training in STEM education must begin at the pre-service level and if needed, practicing teachers must be given professional development opportunities to hone their skills in developing, delivering, and assessing STEM education activities and experiences.

Quality STEM education training requires teaching professionals who are dedicated to developing and delivering engaging STEM education programs. The author agrees with Kennedy and Odell (2014) on what should be included in high quality STEM education programs and curricula. These features should:

- Include rigorous mathematics and science curriculum and instruction;
- At a minimum (if separate STEM courses are not available in all areas), integrate technology;
- Promote engineering design and problem solving— (scientific/engineering) the process of identifying a problem, solution innovation, prototype, evaluation, redesign — as a way to develop a practical understanding of the designed world;
- Promote inquiry — the process of asking questions and conducting investigations — as a way to develop a deep understanding of nature and the designed world (NSTA 2004);
- Be developed with grade-appropriate materials and encompass hands-on, minds-on, and collaborative approaches to learning;
- Address student outcomes and reflect the most current information and understandings in STEM fields;
- Provide opportunities to connect STEM educators and their students

with the broader STEM community and workforce;

- Provide students with interdisciplinary, multicultural, and multiperspective viewpoints to demonstrate how STEM transcends national boundaries, providing students with a global perspective;
- Use appropriate technologies such as modeling, simulation, and distance learning to enhance STEM education learning experiences and investigations;
- Be presented through both formal and informal learning experiences;
- Present a balance of STEM by offering a relevant context for learning and integrating STEM core content knowledge through strategies such as project-based learning.

Issues in STEM Education

The term "STEM" is a relatively new term in the U.S. from the late 1990s (Li et al., 2020), and therefore trends and issues in STEM education would be considered relatively new. However, the author believes there are issues related to developing and implementing K-12 STEM in the U.S. The key issues would focus on the following questions:

1. Is STEM education really needed?
2. What are the best practices in developing and delivering STEM education?
3. How do we improve students' achievement in the STEM fields?
4. How do we inspire students to pursue a career in STEM?
5. How do we best prepare STEM education teachers?

Issue 1. The need for STEM education is questioned

Is STEM education really needed? Yes, STEM education is needed as it helps prepare all students for living and working in the 21st century and pursuing a career in STEM. Reeve (2021) discusses that the need for STEM Education is now more than ever. He states three key reasons why STEM education is needed: (1) STEM education is needed to help students get interested in STEM careers as a STEM-educated workforce helps to keep a country competitive in the global economy, (2) STEM is involved in almost everything, and (3) Many of the world's problems (e.g., climate change, food security, clean drinking water, and the Covid-19 pandemic) will be solved by STEM professionals working together.

STEM education is needed as it can help K-12 students get interested in pursuing a career in STEM. The U.S. needs a STEM-educated workforce. Burke and Okrent (2021) in their executive summary of the report on *The STEM Labor Force of Today: Scientists, Engineers, and Skilled Technical Workers* note that "including workers of all educational backgrounds and the wide variety of occupations that require significant STEM knowledge and expertise the STEM workforce represented 23% of the total U.S. workforce in 2019." They further note that a little over half of the STEM workers do not have a bachelor's degree and work primarily in health care (19%), construction trades (20%), installation, maintenance, and repair (21%), and production occupations (14%) (para. 1).

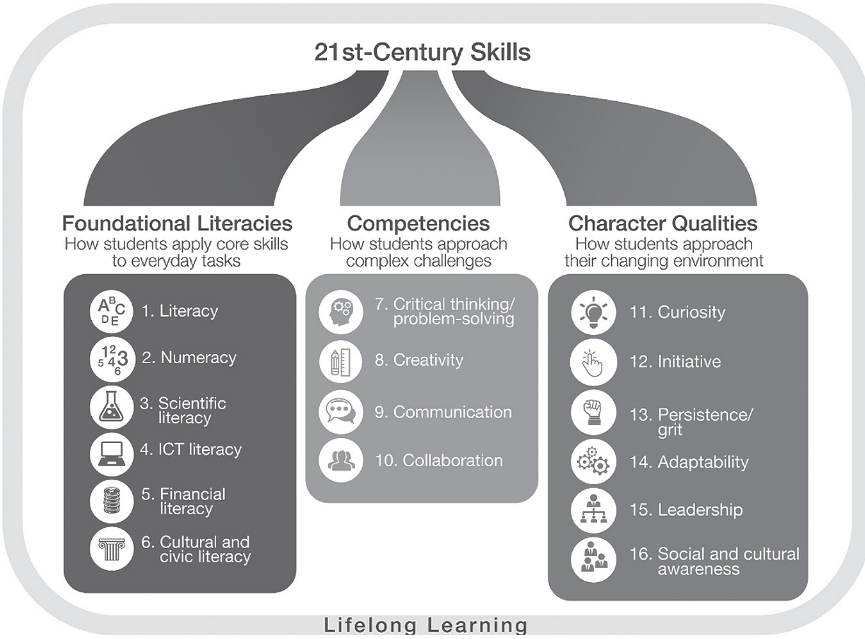
STEM education can help bring STEM professionals from around the world together to address world problems. Soler and Dadlani (2020) make the argument that many of the problems resulting from the COVID-19 crisis have a root cause in science literacy, and they believe "scientific literacy" is a 21st century skill required of today's student. They make the point that the immediate and global need for understanding science in the face of a pandemic has never been more urgent, and that most people not involved in STEM would not even know the basics related to a pandemic. They note that "before the pandemic, 81% of Americans could not name a living scientist. Today scientists are household names appearing daily on prime-time television" (para 4).

Soler and Dadlani (2020) further support the idea that teaching the STEM skills related to science, technology, and engineering for the real world has never been more important. They note that "in the Fourth Industrial Revolution, if we want our students solving the world's biggest challenges, we cannot perpetuate outdated educational systems. We must align public policies and investments in education, science and technology to develop 21st century skills in young people to prepare them for a changing future" (para. 11). In their article, they support the idea of teaching literacy in STEM education as part of the 21st century skills required of all students.

There have been many discussions about what skills are needed by students for the 21st century. Battelle for Kid's (2019) *P21's Frameworks for 21st Century Learning* defines and illustrates the skills and knowledge students need to succeed in work and life. Commonly known as the 4Cs (i.e., Critical thinking. Creativity, Collaboration, and Communication), these learning and innovation skills and other skills (i.e., life and career skills, and information, media, and technology skills) they recommend have been used by many involved in education in the U.S.

This author supports Battelle's model and the model developed by the World Economic Forum (WEF). The WEF model is more complete (see Figure 7), and it shows the skills that the author believes should be taught in STEM education (WEF, 2015). To uncover the skills that students need in the 21st century, they conducted a meta-analysis of research about 21st century skills in primary and secondary education. In doing their research, they identified 16 skills in three broad categories. These categories included (1) foundational literacies that represent how students apply core skills to everyday tasks, (2) competencies to describe how students approach complex challenges, and (3) character qualities that describe how students approach their changing environment.

Figure 7 World Economic Forum 21st century skills



Issue 2. The best practices for developing and delivering STEM education are still being searched for

What are the best practices for developing and delivering STEM education? To address this issue, one needs to consider the development of standards-based STEM curricula, support for STEM education at the university and state levels, and research related to STEM education.

Although there is no national curriculum in the U.S., there are international/national educational standards in each of the STEM disciplines, and most states have adopted these standards to build their state STEM programs and curricula; these would represent *the best practices in developing and delivering STEM education*. Developing "standard-based" STEM curricula can help improve student learning in the STEM areas. Developed by professional organizations and associations these educational standards identify the content to teach at various grade levels. These educational standards that address the concepts of STEM can be freely accessed on the Internet and include:

- Science. Next Generation Science Standards (NGSS): https://www.nextgenscience.org
- Technology and Engineering. ITEEA Standards for Technological and Engineering Literacy: Defining the Role of Technology and Engineering in STEM Education (STEL). https://www.iteea.org/stel.aspx.
- Mathematics. Common Core State Standards Initiative: http://www.corestandards.org/Math

In addition, in the U.S., national STEM curricula programs have been developed, but there is little data related to these programs and to the impact they have on students learning STEM. Again, the U.S. has no national curriculum, but there are a few notable national curriculum programs that focus on STEM education, and the author believes these represent the best practices in developing and delivering STEM education. For example, a brief review of these programs would include:

- Project Lead The Way (PLTW) - https://www.pltw.org
- ITEEA's Engineering by Design (EbD) - https://www.iteea.org/STEM-Center/EbD.aspx
- Engineering is Elementary (EiE) - https://www.eie.org

Project Lead The Way (PLTW) is an American nonprofit organization that develops STEM curricula for use by U.S. elementary, middle, and high schools. To use their curriculum, schools must pay a participation fee and teachers who use their curriculum must complete their professional development training. Currently, they offer a variety of pathways, programs, and related courses. For example, at the high school level they have developed programs in engineering, computer science, and biomedical science. Examples of course titles from these three programs include: Introduction to Engineering Design, Computer

Integrated Manufacturing, Computer Science Essentials, and Principles of Biomedical Science.

ITEEA's Engineering byDesign (EbD) offers a comprehensive, K-12 solution for Integrative Science, Technology, Engineering, and Mathematics (I-STEM) education. They offer standards-based K-12 STEM curricula and require membership and training to use their curriculum. Their curriculum promotes constructivism and problem/project-based learning. Examples of course titles from their program include Exploring Technology, Invention and Innovation, Foundations of Technology and Engineering and Technological Design.

Engineering is Elementary (EIE) is a curricula division of the Boston Museum of Science. They develop research-based, classroom-tested programs that empower children to become lifelong STEM learners and passionate problem solvers. They offer PreK–8 engineering and computer science curricula. To use their curricula, the teacher is paired with an educator that provides professional development to show teachers how to implement their curricula.

A best practice in developing and delivering STEM education would relate to having it supported at the state level as it is already supported at the national level. In the U.S., most states recognize the importance of STEM in their state, and most have developed websites that provide resources to support STEM education (National PTA, n.d.). For example, in the state of Utah, the STEM Action Center (https://stem.utah.gov) is Utah's partner in promoting STEM through the identification and support of best practices and leveraging of resources across education, industry, government, and community partners to support economic prosperity. For example, to help bring STEM to every Utah home, school, and community to build a brighter future, they offer grants related to STEM education, STEM events and activities, including STEM competitions for students, and STEM lesson plans for teachers.

At the university level, the Network of STEM Education Centers (NSEC) has been established by The Association of Public and Land-grant Universities (APLU, n.d.) to support the work that STEM Education Centers are doing to improve undergraduate education. As of August 2021, NSEC currently links 213 STEM Education Centers/Institutes/Programs (SEC) at 170 institutions. The purpose of this network is to (NSEC, n.d.):

1. Build a learning, research, and implementation network for centers via conferences, workshops, communications, staff interactions, and an online platform.
2. Showcase celebrating and understanding the work of centers that are transforming undergraduate STEM education via case studies, research on center impacts, and center profiles.
3. Serve as a resource and catalyst for centers, policy-makers, funders, administrators, and the public on what works in STEM education via a national online platform of effective practices and programs, a directory of experts in STEM education, and research on effective center and institutional practices, and center impacts.
4. Create a coalition of actors that can address and engage in practices that are cross- and multi-institutional via seed grants for collaborative research and implementation proposals.
5. Collectively work to improve institutional and national policies which strengthen undergraduate STEM education through guiding documents, participation in national dialogues, and policy statements (NSEC, n.d.).

To examine the issues related to finding the best practices in developing and delivering STEM education would require a review of the scholarship related to STEM education. Li et al. (2020) did an extensive review of journal publications (i.e., 798 articles) in STEM education and this review presents a good snapshot of the research and trends happening worldwide in STEM education. In their study, they were able to identify 36 journals devoted to STEM Education. Key findings from their research show:

- Tremendous growth in scholarship in the field of STEM education from 2000 to 2018.
- STEM education research has been increasingly recognized as an important topic area and studies were being published across many different journals.
- Scholars still hold diverse perspectives about how research is designated as STEM education.
- The top five journals in terms of the number of STEM education publications are the *Journal of Science Education and Technology, Journal of STEM Education, International Journal of STEM Education, International Journal of Engineering Education,* and *School Science and Mathematics*.
- About 75% (depending on the method) of contributions were made by authors from the USA, followed by Australia, Canada, Taiwan, and the UK.

The top topic category in their study was related to "goals, policy, curriculum, evaluation, and assessment" in STEM education. The next highest category was "K-12 teaching, teacher and teacher education" followed closely by "K-12 learner, learning, and learning environment" (Li et al., 2020). The author believes a review of the scholarship in these articles can help to show what are the best practices in developing and delivering STEM education today.

In addition, *The Future of Jobs Report 2020* (World Economic Forum, 2020) listed what they believe will be the top 15 skills for 2025. The author believes these skills (shown below) can be taught in a well-designed STEM education course or program and represent the best practices in developing and delivering STEM education. Those involved in developing and/or delivering STEM education should try to build these skills into the training.

1. Analytical Thinking and Innovation
2. Active Learning and Learning Strategies

3. Complex-Problem Solving
4. Critical Thinking and Analysis
5. Creativity, Originality, and Initiative
6. Leadership and Social Influence
7. Technology Use, Monitoring, and Control
8. Technology Design and Programming
9. Resilience, Stress Tolerance, and Flexibility
10. Reasoning, Problem-Solving, and Ideation
11. Emotional Intelligence
12. Troubleshooting and User Experience
13. Service Orientation
14. System Analysis and Evaluation
15. Persuasion and Negotiation

Issue 3. Improving student achievement in STEM requires a major reform

Improving students' achievement in the STEM fields will require a major reform in how the U.S. educates its youth. It will require making STEM education a priority at all levels of education and it will require STEM activities, experiences, and lessons that engage students.

The *STEM Smart Brief* (n.d.) notes that for effective K–12 STEM instruction to become the norm, schools and districts must be transformed. They note there are many ways to increase student interest and motivation in science, mathematics, and engineering, including

- relating science to students' daily lives,
- employing hands-on tasks and group activities,
- using authentic learning activities,
- incorporating novelty and student decision-making into classroom lessons, and

- ensuring that STEM curricula focus on the most important topics in each discipline.

The author agrees with this list and realizes that it will be a challenge for many educators as they look for the best ways to engage students in the learning process. In addition, the National Research Council (2011) developed a publication that focused on identifying effective approaches to delivering K-12 STEM education. These goals (listed below) are still relevant, and the author believes that meeting these goals can help improve the achievement of STEM education in the U.S.

> Goal 1: Expand the number of students who ultimately pursue advanced degrees and careers in STEM fields and broaden the participation of women and minorities in those fields.
> Goal 2: Expand the STEM-capable workforce and broaden the participation of women and minorities in that workforce.
> Goal 3: Increase STEM literacy for all students, including those who do not pursue STEM-related careers or additional study in the STEM disciplines.

Issue 4. Inspiring students to pursue a career in STEM requires more teachers' active involvement

Inspiring students to pursue a career in STEM will require that teachers involved in STEM education actively teach about STEM careers, and this should begin at an early age. As *The STEM education strategic plan, charting a course for success: America's strategy for STEM education* (White House, 2018) notes, "Basic STEM concepts are best learned at an early age—in elementary and secondary school—because they are the essential prerequisites to career technical training, to advanced college-level and graduate study, and to increase one's technical skills in the workplace. Increasing the overall digital literacy of Americans and enhancing the STEM workforce will necessarily involve the entire U.S. STEM enterprise" (p. v).

Teaching students about STEM careers will require that teachers learn about STEM careers and know that many of the STEM careers do not require a college degree. As previously noted, a STEM-educated workforce is needed for a nation to stay competitive in the global economy, and many require a four-year or graduate college degree. For example, an engineer, architect, computer scientist, or medical doctor are all STEM careers that require college and/or advanced training.

It is important for teachers to note to students that STEM fields requiring college offer many different specializations and often provide graduates with higher pay when compared with those STEM careers not requiring college. For example, students interested in science can pursue programs in biology and chemistry, while aspiring engineers can explore fields like electrical engineering and mechanical engineering. Payne (2022) notes that students with strong math and science skills should consider pursuing a college career in the STEM disciplines and professional fields. She provides examples of STEM college careers to pursue including those related to:

- Astronomy
- Biology
- Chemistry
- Computer Science
- Electrical Engineering
- Geology
- Information Technology
- Math
- Mechanical Engineering
- Physics

However, teachers must realize that not all STEM careers require a four-year or advanced college degree. While some STEM careers require an associate degree, many only require completing an approved career and technical education (vocational) pathway. Examples of such STEM careers include those in the healthcare professions, any type of technician, and those related to manufacturing and construction. For, example, shown below is the Indeed Editorial Team (2021) list of 15 STEM jobs that do not require a bachelor's degree.

1. Veterinary assistant
2. Electronic assembler
3. Nursing assistant
4. Pharmacy technician
5. Computer user support specialist
6. Accounts payable specialist
7. Ultrasound technician
8. Graphic designer
9. Machinist
10. Plumber
11. Electrical technician
12. Forester
13. Dental lab technician
14. Web developer
15. Dental hygienist

Issue 5. Most teacher education programs are still focused on preparing teachers in a specific STEM discipline

Teachers who teach some aspect of STEM should be familiar with the basic concepts and practices of all the STEM disciplines. Unfortunately, this is often difficult to achieve as most teacher education programs in the U.S. are still focused on preparing teachers in a specific STEM discipline (e.g., science education or technology and engineering education).

In theory, STEM education can be taught by any teacher if they strive to show the connections of the STEM disciplines. However, the author believes it is best taught by teachers who have a background in one or more of the STEM disciplines. For example, at the secondary education level (i.e., grades 6-12) math, science, and technology and engineering teachers can bring STEM to life. But this often requires them to step a little outside their comfort zone as they must learn about the content and practices in the other disciplines they are least familiar with. Perhaps the best teachers of STEM are those at the elementary level (i.e., K-5) as they often teach in a self-contained classroom and can easily connect the components of STEM. For example, an elementary teacher can use an activity that requires students to design, build, and test a parachute that carries a small object to the floor. In this activity, students can learn about aerodynamics (science), the parachute (technology), using an engineering design problem-solving process (engineering), and data collection and measurements (mathematics).

As it is a relatively new area, a major issue associated with STEM education would be related to how to move forward in U.S. education. Recently, major U.S. organizations involved in STEM education (i.e., Advance CTE, the Association of State Supervisors of Mathematics, the Council of State Science Supervisors, and the International Technology and Engineering Educators Association) published a joint document entitled *STEM4: The power of collaboration for change* (Advance CTE et al., n.d.). In this document, they identified three main principles to drive and implement outstanding STEM education research and practices. To help move STEM education forward in P-12 education in the U.S., key stakeholders should follow these principles that provide sound guidance. The three main principles noted in the report to drive STEM education forward include:

- Principle 1: STEM education should advance the learning of each individual STEM discipline,

- Principle 2: STEM education should provide logical and authentic connections between and across the individual STEM disciplines, and
- Principle 3: STEM education should serve as a bridge to STEM careers (p. 3).

Conclusion

At the K-12 level, STEM education is a teaching and learning approach that helps connect the disciplines of science, technology, engineering, and mathematics. An education in STEM can help get students interested in pursuing a career in STEM as a STEM-educated workforce is needed to stay competitive in the global economy.

Although many of the top universities are in the U.S., the U.S. does not perform that well in STEM education at the K-12 level. Compared with the rest of the world, U.S. students only have average performance on national and international assessments. There is room for improvement in the U.S. in K-12 STEM education, and the author believes there are five issues (stated earlier) that must be considered to move K-12 STEM forward.

To become a leader in K-12 STEM education, the U.S. must continue to make it a priority in education, and make sure practicing teachers and in-service teachers learn about what is needed to develop and implement effective STEM programs. To become a leader in STEM education will require all involved in it, including administrators, and university teacher preparation programs to build STEM education programs that are standards-based and developed on the best evidence-based practices.

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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 FINLAND 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)

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STEM education system/ frame-work	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)

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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)

Comparison Components	Countries									
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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)

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)
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

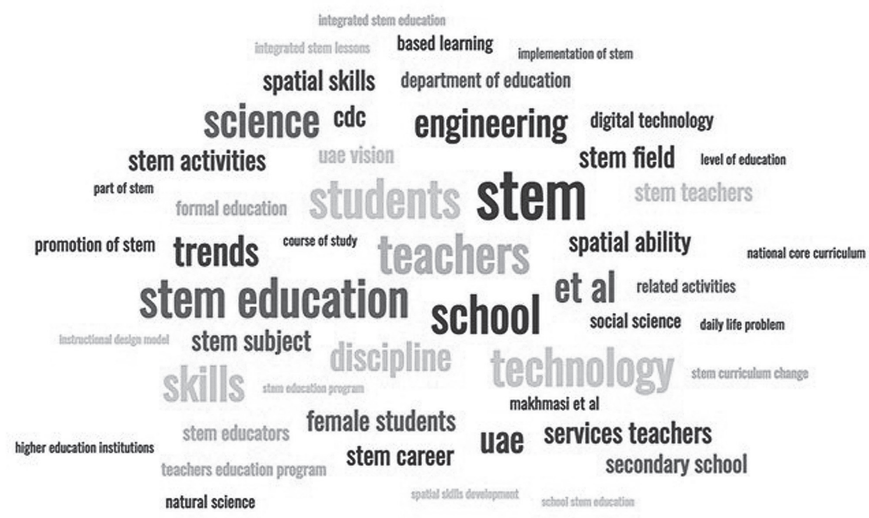
In this section, major trends and issues in STEM education among the 10 countries are discussed and compared in terms of the beforementioned aspects such as contexts and status of STEM education. In this book, “trend is defined as “a general direction in which something is developing or changing” and “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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