Navigating the Future:
A Comparative Analysis of Global STEM Policies and Directions for Sweden

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EXECUTIVE SUMMARY

Commissioned by the Confederation of Swedish Enterprise, this report provides a comprehensive analysis of science, technology, engineering, and mathematics (STEM), and research and innovation policies of 12 of Sweden's comparators. This includes fellow Nordic states (Finland, Norway, Denmark, and Iceland) and other advanced economies from Europe (the Netherlands, Germany, and France), the Anglosphere (United States, United Kingdom, and Australia), and East Asia (Japan and South Korea).

This report aims to inform STEM policy development in Sweden. It covers a wide range of sectors, functions, and practices, commencing with mathematics and science at school. The STEM in school section explores participation and performance in mathematics and science, including pedagogical approaches, teacher education, curriculum, and the features and infrastructure of school systems. It emphasizes the importance of high-quality education, resolution of disparities for girls and under-represented groups, and quality resources and learning environments that engage students. The second section explores STEM in vocational education and training (VET) and higher education, exploring participation and graduation rates in STEM disciplines, policy provisions, and strategies to enhance quality STEM education and training. The report then shifts to consider STEM research and innovation. This section examines comparator's national research priorities, research and development expenditures, output, and innovation in STEM fields. It highlights the importance of research effort and education-industry partnerships for economic dynamism, together with societal wellbeing. The report briefly examines the STEM labour market in terms of demand for STEM knowledge and skills in industry, and the multi-layered structures that govern and facilitate STEM ecosystems. It concludes with a small number of cases that illustrate the range of institutions facing STEM shortages in Sweden.

This report highlights seven STEM policy objectives, including increasing interest, participation and performance in school mathematics and science, improving public scientific literacy and digital skills, increasing participation and performance in VET and higher education STEM disciplines, increasing STEM research effort and excellence, and enhancing STEM innovation and commercialization. For each objective, the report extracts policy solutions from comparator's STEM and research and innovation policies (Figure 1).

The first four objectives primarily concern science and mathematics in school. The first objective advances policy solutions that enhance interest in science and mathematics through effective communication and targeted interaction with students. The second objective aims to increase participation and performance in school mathematics and science, calling for a high-quality education system and pedagogical improvements. This suggests policy solutions including comprehensive pre-service and in-service teacher training, curriculum, addressing disparities for girls and under-represented groups, improving infrastructure, providing adequate school learning resources and education-industry collaborations (e.g., internships).

The third objective seeks to improve public knowledge of science, and scientific literacy and digital skills, highlighting the importance of public engagement and lifelong learning. The fourth objective targets elevating participation and performance in STEM disciplines within VET and higher education, with policy solutions stressing the need for quality systems and institutions, effective STEM teaching, faculty development, diverse program offerings, and investment in infrastructure and learning resources.

Figure 1
Summary: STEM Policy Objectives and Solutions from Comparative Analysis

Objective 1	**Increasing interest in science and mathematics**
Solutions	- communication and interaction with students (including target groups)
Objective 2	**Increasing participation and performance in school mathematics and science**
Solutions	- quality school education system and schools - pedagogy (mathematics, science, technology) (includes personalized support and coaching) - teachers (pre-service teacher education; in-service professional development; 'in-field'; recruitment and retention; school climate; shortages) - curriculum (mathematics, science, technology) (content, sequence, instruction time) - general employability skills - disparities (girls; under-represented; metropolitan/non-metropolitan) - physical and digital infrastructure (including laboratories, libraries, and internet) - school learning resources (mathematics, science, technology) - school education system investment (financing) - out-of-school learning environments - internships (work experience and VET for school students) - education-industry collaborations
Objective 3	**Increasing public knowledge of science, and life-long scientific literacy and digital skills capability**
Solutions	- communication and interaction with the public (including target groups) - scientific literacy and digital skills capability - lifelong learning
Objective 4	**Increasing participation and performance in VET and higher education STEM disciplines**
Solutions	- quality VET and higher education systems and institutions - teaching (STEM teaching and learning pedagogy) - faculty (STEM lecturers/researchers, STEM research supervisors) (education; institutional climate; shortages) - programs (pre-STEM, bridging and STEM curriculum) (content, sequence, instruction time) - international education provision (STEM, other) - general employability skills and lifelong learning - disparities (women; under-represented; metropolitan/non-metropolitan) - investment in VET and higher education systems (financing) - physical and digital infrastructure (laboratories, instruments and devices, supercomputers, databases, measuring instruments, libraries, museums, archives) - learning resources (STEM) - internships (work integrated learning, apprenticeships, PhD students) - entrepreneurship programs - higher degrees by research
Objective 5	**Increasing STEM research effort and excellence including national priorities, grand challenges, and societal issues**
Solutions	- research and development financing: public and private (investment) - faculty/researchers (higher education and research institutes and industry) (recruitment, retention/precarity, grant funding) - disparities (women; under-represented; metropolitan/non-metropolitan) - research and development effort (basic and applied; STEM; interdisciplinarity; HASS) - United Nations Sustainable Development Goals for 2016-2030 - physical and digital infrastructure (laboratories, instruments and devices, supercomputers, databases, measuring instruments, libraries, museums, archives) (international, European, national, local) - internationalisation (global science; European and international networks; mobility) - promotion and dissemination of research insights (science communication; open science)
Objective 6	**Increasing research, innovation, and commercialization**
Solutions	- research and development investment (financing) - innovation and commercialization investment (public and private capital) - intellectual property generation and exploitation (including patents) - start-up incubation - innovation offices - public-private-partnerships and industry-academia collaboration - tax incentives - legislation and regulation
Objective 7	**Facilitating economic dynamism and competitiveness by ensuring industry demand for STEM knowledge and skills are met (i.e., STEM-specific occupations, and others more generally)**
Solutions	- education-industry collaborations (including public-private partnerships) - government-education-industry collaborations

Objectives five through seven delineate ambitions for advancing STEM research and innovation, and aligning educational outcomes with industry needs. The fifth objective focuses on increasing STEM research efforts and excellence, incorporating a wide range of policy solutions from investment to international collaboration, aimed at addressing national and global challenges. This includes those highlighted in the United Nations Sustainable Development Goals (SDGs). The sixth objective emphasizes enhancing research, innovation, and commercialization through various means such as increased investment, fostering public-private partnerships, encouraging start-up incubation, and streamlining legislation and regulation.

The seventh and final objective concerns facilitating economic dynamism and competitiveness by ensuring industry's demand for STEM knowledge and skills is met. Policy solutions include education-industry collaborations and partnerships between governments, educational institutions, and industry players to align education outcomes with market needs, thereby enhancing employment prospects in STEM fields.

Together these policy solutions provide an evidence-based scaffold for advocacy by the Confederation of Swedish Enterprise for Sweden's new STEM policy development.

INTRODUCTION

This policy research report was commissioned by the Confederation of Swedish Enterprise at a pivotal time as the Swedish Government pursues science, technology, engineering, and mathematics (STEM) policy solutions. It builds on a preliminary policy brief that observed the prevalence of STEM policies in Sweden's comparator countries, identifying STEM policy objectives for school education, vocational education and training (VET), higher education, research and development (R&D), and industry innovation (Freeman, 2023). Intersecting policy domains inject further urgency into assuring STEM knowledge and skills at foundation and advanced levels, including technology, climate, nature and the environment, energy, space, and security. This report observes that migration and industrial relations policy are also relevant. As such, this report is framed around seven STEM policy objectives, intersecting policy domains, and education, training and research sectors as illustrated in Figure 2.

Figure 2
STEM Policy Objectives and Intersecting Policy Domains

	Objectives	Sector
Objective 1	Increasing interest in science and mathematics	School
Objective 2	Increasing participation and performance in school mathematics and science	
Objective 3	Increasing public knowledge of science, and life-long scientific literacy and digital skills capability	Community
Objective 4	Increasing participation and performance in VET and higher education STEM disciplines	VET and higher education
Objective 5	Increasing STEM research effort and excellence including national priorities, grand challenges and societal issues	Research and innovation
Objective 6	Increasing research, innovation and commercialization	
Objective 7	Facilitating economic dynamism and competitiveness by ensuring industry demand for STEM knowledge and skills are met (i.e., STEM-specific occupations, and others more generally)	Industry

Intersecting policy domains

Technology policy	Climate, nature, and environment/energy policy	Space policy	Security policy	Migration policy	Industrial relations policy

This report begins by analyzing trends in school mathematics and science participation and performance, considering educational research to identify key factors. It covers various elements, from pedagogical methods and teacher training at the school level to curricular aspects, modern learning tools, and extracurricular learning settings. The focus then extends to vocational and higher education in STEM, examining student involvement, pedagogy, graduation rates, and policy interventions. Subsequently, the report addresses research priorities, funding, capabilities, and outputs, as well as policies on research and innovation. It highlights areas particularly amenable to governmental action (Freeman et al., 2019) crucial for comprehensive quality education, a robust STEM workforce, impactful research and innovation, and effective collaborations. These themes form the core framework for comparing STEM, research and innovation policies in Sweden and other countries.

Throughout, the report highlights the STEM, research and innovation policy instruments of Sweden's comparator countries aimed at achieving STEM policy objectives (Figure 2). In doing so, it provides a basis for policy borrowing and advocacy. While the ways in which governments conceive STEM varies considerably, there is shared agreement that STEM knowledge, skills and capabilities are vitally important. This includes, amongst other things, "growing our understanding and appreciation of the natural and physical world and the broader universe around us; interpreting and analysing data and information; research and critical enquiry – to develop and test ideas; problem solving and risk assessment; experimentation, exploration and discovery of new knowledge, ideas and products;

collaboration and working across fields and disciplines; and creativity and innovation – to develop new products and approaches" (Scottish Government, 2017, p. 5).

Increasingly, STEM (and STEAM) policies acknowledge that essential knowledge, skills and capabilities extend from science, technology, engineering and mathematics to interdisciplinarity (or integration) and explicit acknowledgement of the importance of the humanities, arts, and social sciences. As the *Finnish National STEM Strategy and Action Plan* states, "[i]n European education and industrial policy, STEM needs are widely identified. The European Commission promotes education that approaches, without limits, the connection of STEM and [information communication technologies] teaching to art, human sciences and social sciences in a multidisciplinary way" (Ministry of Education and Culture, 2023, p. 8).

The release of this report is timely as the Swedish Government advances STEM policy and initiatives within a landscape shaped by significant, shared megatrends: digitization, societal structural shifts, global environmental and resource changes, world order transformation, and normalized risks (Ministry of Science and ICT, 2022, p. 13). Concurrently, there is an escalating imperative at international, national, and community levels to address the United Nations Sustainable Development Goals (SDGs) and confront large-scale, multi-dimensional 'grand challenges' such as climate change, global health and security.

Comparator Country STEM Policies

This report is informed by a close reading of a selection of STEM, research and innovation policies sourced from 12 of Sweden's comparators. This includes fellow Nordic states (Finland, Norway, Denmark, and Iceland), other European countries (the Netherlands, Germany, and France), countries from the Anglosphere (United States, United Kingdom, and Australia), and East Asia (Japan and South Korea) (Appendix 1). This sample of formal policy instruments encompasses diverse forms of documentation, including but not limited to *legislation*, *policies*, *budgets*, *strategies*, *roadmaps*, *agreements*, *reports*, *frameworks*, and *plans*. Determined via government decision-making processes, these instruments are implemented through a multitude of *projects*, *programs*, *guidelines*, and internet-based *materials*. Introduced over time, they are operationalized through supporting texts and schemes that together reflect government political positions, principles, and aspirations.[1]

The selected STEM, research and innovation policies vary significantly in scope, complexity and length, ranging from concise documents of merely two pages to comprehensive compilations exceeding one hundred pages. Some are tailored to address one particular education or research sector (e.g., school, higher education, research, innovation), whereas others adopt a broader view, encompassing most or all sectors. Importantly, the timescale of these texts varies (e.g., five-year plans, and others). Some policies include an evidence base for goals and targets, explicitly referencing contributory research reports, data sources and supplementary inputs. Implementation of all sampled policies necessarily involves collaboration with social partners, including industry.

[1] It is understood that these 12 comparator countries have additional relevant policy instruments and attendant texts, including more recent documentation in some instances that was not identified. This material could be used to supplement the analysis conducted for this report.

Policy Priorities

The analysis reveals that a surprising array of commonalities exist amongst Sweden's comparator countries in terms of broadly defined, government policy priorities, despite important differences in political, economic, social and historical contexts, as well as policy cultures. In many instances, government's presume foundational capabilities and excellence in STEM fields of education at school and post-school levels, as well as extensive STEM research capabilities, activity and infrastructure (see Freeman, 2023).

In advanced Nordic countries government policy priorities include world-class school education, higher education, research, science-industry knowledge transfer, innovation, and the ability to address global, economic, and societal challenges. These countries have long placed a high emphasis on sustaining competitive, innovative business environments, with an additional focus on health, wellbeing, safety, and security. Technological advancements, particularly in digitalization, artificial intelligence, and data sharing, are deemed crucial for the ongoing success and transformation of Nordic economies, businesses, and society. This focus extends to protecting the climate, nature, and environment sustainably. Many of the shared Nordic government policy priorities align with those set for Sweden's Presidency of the European Union in 2023, including security, competitiveness, green and energy transitions. These priorities also resonate with broader issues important to the European Union, such as skills for future competitiveness and growth, the semiconductor shortage, artificial intelligence regulation, sustainability, biodiversity, climate, and digital identity.

In other advanced European comparator countries, government policy priorities similarly include world-class education, skills development, knowledge and research systems, open science (i.e., the dissemination of research outcomes, methods and products), and technology-driven industry growth. For instance, the deployment of artificial intelligence and robotics is a key area of focus. These countries also prioritize collaboration between education, industry, and research institutions, highlighting the importance of knowledge and technology transfer and industrial competitiveness. They also encourage increased European and international collaboration. Research, innovation, and technology are central to their strategies for addressing grand challenges.

Meanwhile, in high-performing Anglosphere countries, government policy priorities are centered around foundational scientific or STEM literacy, such as digital skills, as well as STEM disciplinary skills and knowledge. These countries often frame their policy prioritization as a response to a perceived 'STEM crisis' or 'skills crisis' characterized by declining international performance and competitiveness, and unmet industry demand for STEM skills. Enabling rapid technology advances, such as in artificial intelligence, semiconductors, and quantum technologies, is also a priority. These advancements are considered essential for addressing major challenges related to climate, environment, and health. Policies in the United States and United Kingdom, in particular, anticipate global scientific and technological leadership. For all these Anglosphere countries, STEM capabilities are seen as underpinning national security and defense regimes.

In high-performing East Asian comparator countries, government policy priorities encompass science, technology, and innovation, with a strong emphasis on digitalization and economic competitiveness. These countries also focus on enabling rapid technological advances and prioritize national safety, security, sustainability, and resilience. Their policy priorities are responsive to contemporary social issues, including changing demographics marked by falling birth rates and aging populations. East Asian governments have also prioritized global and national challenges, such as climate change and disaster preparedness. Despite varied external and internal forces, geopolitical considerations and frames of reference, commonalities reflect shared urgent aspirations for high quality school, vocational and education, research excellence, economic prosperity, societal wellbeing and peaceful resolution to global and domestic challenges related to security, energy, climate change, technological advances, emergencies and other disruptions.

MATHEMATICS AND SCIENCE AT SCHOOL

Participation

Participation in mathematics, science (i.e., biology, chemistry, physics) and technology subjects varies by country and region, over time; however, there are no international, standardized datasets for school level fields of education. Differences in participation between countries partly reflect fundamental systemic variance regarding schooling structures including streaming practices, level of compulsion and availability of personalized teaching support. However, they also reflect school students' different attitudes, especially interest, self-efficacy and ability (Palmer, Burke & Aubusson, 2017).

In terms of participation in school mathematics, education research has observed the trend away from advanced mathematics subjects in senior secondary years (Marginson et al., 2013). Relatedly, some studies have observed the growing prevalence of 'math anxiety', or the "feeling of tension, apprehension or even dread that interferes with the ordinary manipulation of numbers and the solving of mathematical problems" (Ashcraft & Faust, 1994, p. 98). Math anxiety can drive school students away from advanced mathematics subjects, impacting their future study and employment pathways, and the STEM pipeline more broadly.[2] In terms of participation in school science, studies have found gender differences in subject enrolments, with girls under-represented in school physics and over-represented in school biology (Corrigan et al., 2023). Other factors, such as socio-economic status background and geographic location, also impact trends in school student mathematics and science participation and learning.

In Sweden, participation at upper secondary school level has consistently been highest overall in social science, and business management and economics programs, rather than natural science or technology programs over the period 2017/18 to 2021/2022 (Table 1). Gender differences are evident at the program level (Table 1), and as students diverge into the higher education preparatory (60% overall), vocational (29% overall) or introductory strand (10% overall). A greater proportion of girls are enrolled in the higher education preparatory than vocational strand (Hartell & Buckley, 2022) (Table 2). Only one in five girls in Sweden, compared to three in eight boys, report expecting to work as an engineer or science professional (OECD, 2019).[3]

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[2] Lau et al. (2022) found that "[c]onsistent associations between math anxiety and math achievement have been observed across countries and age groups, placing math anxiety among other important correlates of math achievement, such as socioeconomic status" (p. 1).

[3] The EU STEM Coalition (2023) reports that multiple factors influence gender disparities in STEM, including educational inequality, outdated curricula, girls' math anxiety, parental expectations and influence, and lack of self-efficacy. Their study concludes that "the underlying factor is the recycling of an unconscious bias that ostracises young girls and women in STEM and ICT specifically" (2023, p. 6).

Table 1
Percentage of Female and Male Applicants to Swedish Upper Secondary Level Programs, Organized by the Average Percentage Different 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.

Source: Hartell & Buckley, 2022.

Table 2
Swedish Upper Secondary School Strand Demographics (2021)

Strand	Total students	Total students (%)	Male students (%)	Female students (%)
Higher education preparatory	218,623	60%	55%	66%
Vocational	105,618	29%	34%	24%
Introductory	37,432	10%	11%	9%

Source: Hartell & Buckley, 2022.

STEM policies typically aim to increase participation in general and advanced school mathematics and science subjects through system-wide reforms, and/or more targeted projects. Frequently such policies (and targeted projects) aim to nurture students' curiosity and encourage enthusiasm for mathematics and science. For example, Denmark's *National Science Education Strategy* aims to ensure that "more children and young people ... take an interest in science subjects in elementary school and choose science-based high school subjects and vocational STEM courses" (Ministry of Education, 2018, p. 7). The *Finnish National STEM Strategy and Action Plan* aims to encourage positive attitudes towards mathematics in early childhood education (e.g., through play and exploratory approaches), and increase participation in advanced mathematics and science at senior secondary level. This strategy also recognises the role that higher education admissions processes play in student choice-making earlier in their learning journey.

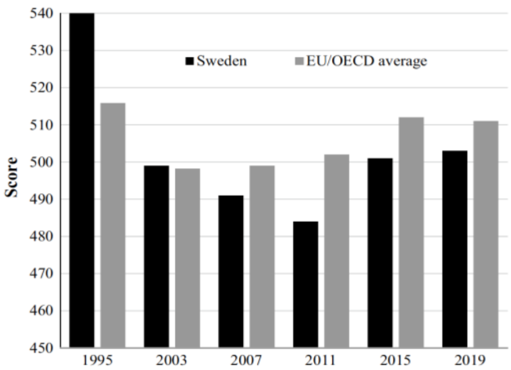
Concurrently, STEM policies aim to engender equitable access and quality across all demographics and schools, encompassing gender, socio-economic and migration status, and geographical location. For example, the *Finnish National STEM Strategy and Action Plan* argues that "equal opportunities and enabling full talent potential according to each person's abilities plays a key role" (Ministry of Education and Culture, 2023, p. 8). In the United States Title 1 and the *Individuals with Disabilities Education Act* (IDEA) aim to advance equity. Australia's *National STEM School Education Strategy 2016-2026* acknowledges inequities in STEM for girls, students from low socio-economic status backgrounds, indigenous students, and students from non-metropolitan areas. Similarly, the Welsh

Government's *Science, Technology, Engineering and Mathematics (STEM) in Education and Training* policy aims to increase interest and participation in STEM generally and more particularly, among girls. The *Science, Technology, Engineering, Mathematics Education and Training Strategy for Scotland* acknowledges that "we need to tackle the gender imbalances and other inequities that exist across STEM education and training including in relation to race, disability, deprivation and geography" (Scottish Government, 2017, p. 4). Germany's *STEM Action Plan 2.0* prioritizes opportunities for girls and women in STEM, arguing that "traditional role models and gender-specific attributions of professions and activities must be structurally broken down" (Ministry of Education and Research, 2022, p. 19). Germany's strategies to encourage girls and women in STEM include Girls Day, the National Pact for Women in STEM Professions, and Success with MINT – New Opportunities for Women funding scheme.

Performance

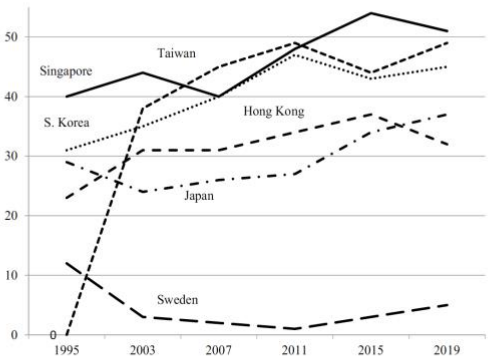
In many advanced countries metrics concerning school mathematics and science performance were limited until the deployment of international student surveys. With these assessments, considered proxies for education quality and predictors of economic growth (Hanushek & Woessmann, 2015; Heller-Sahlgren & Jordahl, 2023), came evidence, questions, and interest in policy solutions.

Figure 3
Sweden and the EU/OECDs Average Score in TIMSS Mathematics (1995-2019), Grade 8 Students



Source: Mullis et al., 2004, 2008, 2012, 2020 in Henrekson and Wennström, 2022.

Figure 4
Percentage of Students in Sweden and the Top-five Societies at the Advanced Proficiency Level of 8th Grade in TIMSS Mathematics (1995-2019)



Source: Mullis et al., 2012, 2016, 2020 in Henrekson and Wennström, 2022.

According to Trends in International Mathematics and Science Study (TIMSS) assessments conducted by the International Association for the Evaluation of Educational Achievement (IEA) since 1995, Sweden's grade 8 students initially performed well in mathematics. However, performance then fell (2003-2011), before recovering somewhat (2015-2019). Throughout the period 2007-2019, Sweden has remained below the EU/OECD average for grade 8 mathematics (Figure 3). By contrast, the performance of grade 4 students in mathematics suggest improvement over the reported period 2007-2019 (Hartell & Buckley, 2022). As illustrated in Figure 4, the percentage of students in Sweden achieving advanced proficiency in mathematics was considerably lower than global leaders, Taiwan, Singapore, South Korea, Hong Kong and Japan. Sweden's TIMSS Advanced results, for final-year secondary school students in mathematics and physics, also reveal dramatic declines over three assessment rounds (1995, 2008, 2015). For Sweden, as for many other advanced economies, the TIMSS assessment results proved cause for concern.

Similarly, Sweden's results on Programme for International Student Assessment (PISA) assessments conducted by the Organisation for Economic Cooperation and Development (OECD). Sweden initially performed well in the first PISA cycle in 2000; however, the drop in 2012 caused 'PISA shock', an experience shared with several others (Ringarp, 2016). Sweden's results corrected to near pre-2012 levels by 2018, with student's proficiency scores in 2018 higher than the OECD mean.[4] However, concern persists in Sweden about the proportion of students performing at the highest levels, as well as differences in performance between students based on demographics. Heller-Sahlgren (2015) reports that the influence of changed student composition, including the proportion of students with Swedish origin, was highest in PISA's science results, and lowest in mathematics, with effects increasing in more recent years as immigration has accelerated.

The most recent PISA results for 15-year old's mathematics, science, and reading proficiency show that Sweden's position changed over the period 2018 to 2022 relative to comparator countries (Table 3). Many countries reported unprecedented decreases as a result of the COVID-19 pandemic, with all Nordic countries, most other European comparators, and the United Kingdom dropping overall rank. By contrast, leading East Asian countries (i.e., Singapore, Macau, Japan, Korea) increased individual test results,[5] and either increased or maintained overall rank positions. School systems that appeared to successfully mitigate COVID-19 induced disruptions typically kept their schools open longer throughout the pandemic, resolved barriers to remote learning, and strengthened parent-school partnerships (OECD, 2023a). From a comparative perspective, in 2022 Sweden ranked #19 globally on the overall PISA score, down from #15 in 2018. These results place Sweden behind global leaders in East Asia (Singapore: #1; Macau: #2; Taiwan: #3; Japan: #4; Korea: #5) as well as Finland (#13) and Denmark (#17), some other European countries (Estonia: #7; Switzerland: #10; Poland: #15), and some Anglophone countries (Canada: #8; Australia: #11; United Kingdom: #14) (OECD, 2019, 2023b). Overall, the extent to which individual country's PISA scores decreased represents widespread, urgent cause for concern as systems endeavour to address learning losses (Table 3).

Table 3
PISA Results by Country (2018, 2022)

Region or grouping	Country	Global Rank (2018 / 2022)	Overall PISA score (2018 / 2022)	PISA overall mathematics score (2018 / 2022)	PISA overall science score (2018 / 2022)	PISA overall reading score (2018 / 2022)
Nordic countries	Finland	#8 / #13	516 / 495	507 / 484	522 / 511	520 / 490
	Sweden	#15 / #19	502 / 488	502 / 482	499 / 494	506 / 487
	Denmark	#16 / #17	501 / 491	509 / 489	493 / 494	501 / 489
	Norway	#21 / #33	497 / 474	501 / 468	490 / 478	499 / 477
	Iceland	#28 / #39	481 / 447	495 / 459	475 / 447	474 / 436
Other European	Netherlands	#14 / #25	502 / 480	519 / 493	503 / 488	485 / 459
	Germany	#17 / #24	500 / 482	500 / 475	503 / 492	498 / 480
	France	#23 / #26	494 / 478	495 / 474	493 / 487	493 / 474
Asia	Singapore	#2 / #1	549 / 560	569 / 575	551 / 561	549 / 543
	Japan	#4 / #4	520 / 533	527 / 536	529 / 547	504 / 516
	Korea	#5 / #5	520 / 523	526 / 527	519 / 528	514 / 515
Anglophone	United Kingdom	#12 / #14	504 / 494	502 / 489	505 / 500	504 / 494
	Australia	#19 / #11	499 / 497	491 / 487	503 / 507	503 / 498
	United States	#22 / #18	495 / 489	478 / 465	502 / 499	505 / 504

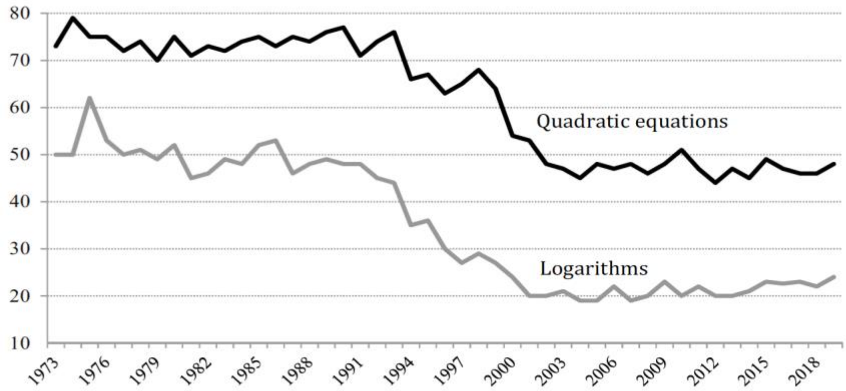
Source: OECD, 2019, 2023b. Note: Red = decrease between 2018 and 2022; Green = increase between 2018 and 2022.

4 For mathematics and science, Sweden's proportion of 'top performers' in 2022 (defined as achieving level 5 or 6 in PISA) (10%) was higher than the OECD average (8.7% and 7.5% respectively). At the same time, Sweden's proportion of students achieving minimum proficiency levels (defined as achieving level 2 or higher) (27.2% and 23.7%) was lower than the OECD (31.1% and 24.5%) (OECD, 2023a).

5 Marginally against this trend, Denmark's overall science score increased slightly, from 493 (2018) to 494 (2022) (OECD, 2023b).

Other assessments highlight related challenges, including diagnostic tests conducted with commencing engineering students at Chalmers University of Technology. Despite having each completed school-level science and technology programs (and mathematics level D), incoming university student's capacity to solve logarithms and quadratic equations progressively decreased over the period 1973 to 2019 (Figure 5).

Figure 5
Percentage of Correct Answers in the Section on Logarithms and Quadratic Equations in Chalmers' Diagnostic Tests in Mathematics (1973-2019)



Source: Pettersson, 2015 in Henrekson and Wennström, 2022.

Similarly, studies have raised concerns regarding the gap between senior secondary student's mathematics and science proficiency and university entrance requirements. Brandell et al. (2008), in *The Widening Gap—A Swedish Perspective*, identify potential variables including "the curriculum gap; perceptions of knowledge and learning of mathematics; students' encounters with proofs and proving; and … recent and historical development of the educational system" (pp. 38-39). The influence of university prerequisites on school science and mathematics education, curriculum and performance has been reported elsewhere (Marginson et al., 2013). While undertaken before the most recent curriculum revision, Brandell et al. (2008) conclude that "the complexity of the situation is such that no easy solutions can be found and only long-term reforms taking into account both [school and university] levels can lead to essential improvements" (p. 53).

STEM policies typically aim to improve mathematics and science performance, as per national and international assessments (PISA, TIMSS), overall, for the high achievers, and for the disadvantaged. Enhancing performance for all students is vitally important to ensure a baseline level of numeracy, digital and scientific literacy to meet the demands of society and the labour market. At the same time, enhancing performance in advanced mathematics is essential to ensure participation at necessary levels in STEM fields in higher education, research, industry, and innovation spheres. Clearly, advanced science and mathematics is foundational for related policy domains: technology, climate, nature and the environment, energy, space, and security.

Complementing the United States' *Raise the Bar: Lead the World* commitment, the Department of Education's *Best Practices Clearinghouse* presents materials to support students, particularly historically disadvantaged students, access education. This includes efforts to address student's COVID-related learning deficits (e.g., Engage Every Student Initiative for out-of-school-time support). Also in the United States, 21st Century Community Learning Centers provide enrichment, afterschool, and summer learning programs.

Swedish Projects

Sweden's three major mathematics education projects over the 60-year period from 1960 to 2018 were New Math (1960-1975), PUMP[6] (1970-1980) and Boost for Mathematics (2012-2016). The detailed account by Prytz (2021) reports that the New Math project had grand ambitions. Largely derived from one psychology-based theory of mathematics teaching and learning, New Math recognised the changing role of mathematics in modern society, research and development, urbanisation and automation. The smaller scale PUMP project was introduced to "resolve a critical situation: poor student outcomes and inefficient teaching in arithmetic" (Prytz, 2021, p. 1041). Reflecting concerns regarding the quality of New Math curriculum and textbooks, the PUMP project aimed to help teachers plan by providing detailed diagnostic materials for arithmetic (Years 1-6).

More recently, the Boost for Mathematics project (*Matematiklyftet*), by the National Agency for Education and National Centre for Mathematics Education, Gothenburg University, delivered in-service professional development for Swedish mathematics teachers (Years 1-12). The Boost project involved peer learning, professional development by mathematics education researchers, subject-specific modules (i.e., arithmetic, geometry, algebra, functions), and general modules (i.e., problem solving, digitalization, language in mathematics). It aimed "to achieve a changed teaching culture with a focus on developing teaching, and to achieve a changed in-service training culture (*fortbildningskultur*)". Furthermore, "the specific goals for the teachers were to achieve a higher degree of reflection about their teaching decisions, and to have a wider set of teaching methods and attitudes (*förhållningssätt*)" (Prytz, 2021 p. 1042). Lindvall et al. (2022) report that the Boost for Mathematics project "corresponds well with core critical features of high-quality teacher [professional development] and mathematics instruction ... and the results indicate that it has had a small but statistical[ly] significant impact on teachers' instructional practices" (p. 744). STEM projects have also been undertaken by government, industry, schools and universities. This includes individual projects, such as the Royal Swedish Academy of Engineering Sciences initiative, *Tekniksprånget*, that aimed to increase interest in STEM fields through internships and other actions.

Importantly, Hartell and Buckley (2022) acknowledge that "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" (p. 342). For example, more generalized reforms, not specifically related to, but relevant to mathematics education, were introduced by the Swedish government in response to concerning PISA test results in the early 2000s. For example, the National Education Agency (*Skolverket*) observes "access to teachers, teachers' skills and competent school administration, and standardization in judging and grading" (2004, p. 12), referencing Sweden's goal-related grade system, teacher qualifications, and teachers' familiarity with curricula and grade criteria. Skolverket also recommends clearer goals, evaluation of student performance, improved teacher education, teacher certification, and classroom management (i.e., discipline) (Swedish Government Official [SOU], 2014 reported in Ringarp, 2016). The government also pursued comparative policy studies, examining school reforms in other Nordic countries, Canada, and South Korea concerning teaching (i.e., intake, qualifications, certification, status).

[6] PUMP, or *Processanalyser av undervisning i Matematik/Psykolingvistik*, means 'Process analysis of teaching in mathematics and psycholinguistics'.

Pedagogy

"the most relevant knowledge [for teachers] will be that which concerns the particular topic being taught and the relevant pedagogical strategies for teaching it … If the teacher is to teach fractions, then it is knowledge of fractions and perhaps of closely associated topics which is of major importance … Similarly, knowledge of teaching strategies relevant to teaching fractions will be important"
(Byrne, 1983, p. 14)

Pedagogy, the theory and practice of teaching, is concerned with how content is delivered, how students engage, and how teachers create an environment conducive to learning. Pedagogy encompasses content sequencing (i.e., new topics/sub-topics; foundational > complex concepts), instructional methods (i.e., direct instruction, collaborative groupwork), assessment practices (i.e., formative or continuous, summative), technology (e.g., scientific instruments, calculators, devices, large language models), classroom management, and inclusion strategies (e.g., cultural and social diversity). Over time, pedagogical approaches to mathematics and science teaching have trended away from traditional didactic methods ("teacher-led talking from the front") and rote learning to problem-based learning (Hattie, 2009, p. 205).[7] Jäder et al. (2018) describe rote learning as "an imitative approach that focuses on procedures rather than on problem solving and reasoning" (p. 1120). Studies have shown how problem-based learning cultivates higher-order conceptual understanding (Hattie, 2009);[8] however the Australian Mathematical Sciences Institute (AMSI) caution that "[m]astery of mathematical approaches is needed before student problem solving can be effective" (p. 2). The research literature also highlights inquiry-based approaches, and methods that encourage creativity and critical thinking. Studies illustrate that pedagogical approaches do not necessarily fall neatly into oppositional categories (e.g., expository/discovery; direct instruction/inquiry-based; teacher-centred/student-centred) (Hiebert & Grouws, 2007), with benefits dependent on multiple factors.

"In debates about schooling, and especially mathematics teaching, it is often claimed that nothing changes. The traditions are strong and teachers do as their own teachers did. Evident facts disprove such claims"
(Bergsten & Grevholm, 2004, p. 123)

In the context of Sweden, pedagogical approaches have been extensively researched (Nilsen & Gustafsson, 2016; Jäder et al., 2020). For example, Hemmi and Ryve (2015) report that Swedish mathematics teachers emphasize "everyday connections and everyday problems" (p. 516). Henrekson and Wennström (2022) acknowledge the importance of schools and teachers giving students access to accumulated knowledge, arguing that "the postmodern social constructivist view of knowledge and its associated pedagogy of student-centred discovery and experimentation undermine the quality and functioning of the Swedish school system" (p. 162).

Other studies have analyzed the extent to which pedagogy has been determined by government, contextualised for local education environments, and deployed by teachers to teach mathematics (i.e., specificity vs autonomy). While many studies emphasize the importance of teacher autonomy in teaching national curriculum, Van Steenbrugge and Ryve (2018) observe that "[t]he role of the teacher in the classroom is connected to traditions of a specific view regarding the empowerment of

[7] Merritt et al. (2017), extending previous studies, define *problem-based learning* as "an educational instruction method that fosters learning and the development of 21st century competencies and skills … through problem solving and the integration and application of knowledge in real-world settings" (p. 1). They differentiate this from constructivist approaches such as *project-based science learning* involving "projects that focus on problems in their real-life settings", with "the principal features … include[ing] 'constructing knowledge through trial and error,' 'learning by doing' and 'applying new knowledge to new circumstances'" (p. 1).

[8] De Ron et al. (2022) found "an almost equal distribution of research which views problem-solving as an *aim* for mathematics education versus research which views problem-solving as a *means* for learning mathematics" (p. 1; emphasis added).

teachers in Sweden" (p. 803).[9] They recommend the introduction of additional "supports [for teachers] that are directive in nature ... such as use of ... lesson slides to structure the lessons, principles for discussions, and the use of exit tickets" (p. 810). Debates concerning Swedish school and teacher autonomy, empowerment, and utility of pedagogical tools continue.

"Achieving Academic Excellence,
which includes recovery of lost instructional time, an emphasis on literacy and math concepts, rigorous learning standards, and well-rounded learning opportunities that include early childhood education; science, technology, engineering, and math (STEM); and the arts"
(Department of Education, 2023a, p. 1)

Several comparator countries reference in their STEM policies the trend toward evidence-based, pedagogical innovation in school education. Analysis of international STEM policies by Freeman et al. (2014) concludes that "the most successful countries have instituted active programmes of reform in curriculum and pedagogy focused on making science and mathematics more engaging and practical, through problem-based and inquiry-based learning, and emphases on creativity and critical thinking" (p. 10). Such policy emphasis is clear in many countries. For instance, the United States policy, *Raise the Bar: Lead the World*, articulates a federal commitment to "supporting innovative teaching and learning models; promoting more and better individual and small-group support for students" (2023b, p. 1). Evidence based pedagogical strategies are explored through their National Center for Education Research and distributed in Comprehensive Center Network (CCNetwork) resources (e.g., *Guide to Accelerated Learning*). The United States government policy emphasizes "STEM-linked pedagogies including experiential learning and computational thinking" (Marten, 2022, p. 1). The LUMA Centre Finland,[10] an umbrella organization focused on science education comprising regional centres located in Finnish universities, places significant emphasis on empirically substantiated STEM pedagogies and teacher education. Similarly, Norway's *Science for the Future* invests in specialized teacher support centers. Japan's *6th Science, Technology and Innovation Basic Plan* promotes exploratory learning, encouraging pedagogical frameworks that foster curiosity and facilitate inquiry-based approaches to problem-solving. Similarly, Australia's *National STEM School Education Strategy 2016-2026* promotes enhanced pedagogy through curated teaching modules. Scotland's strategy, underpinned by the 2016 *Making Maths Count* group report, foreshadows capacity building to "deliver excellent STEM learning so that employers have access to the workforce they need" (2017, p. 9). This agenda includes "promoting skills progression in STEM learning, including through engagement with the curriculum benchmarks and bringing real-life examples from the world of business and research into STEM learning" (2017, p. 15).[11]

Moreover, STEM policies and related projects indicate a trend towards integrated teaching methods. Japan's *6th Science, Technology and Innovation Basic Plan*, for instance, includes STEAM, "[c]ross-disciplinary education to utilize learning in each subject such as Science, Technology, Engineering, Art(s), Mathematics, etc. for finding and solving problems in the real world" (2021, p. 13). Similarly, Finland's strategy references the STEAM concept, understood to include 'arts', "which identifies the link between STEM and other sciences, such as arts and humanities" (2023, p. 9). Such STEM policies aim to strengthen teaching, learning and assessment by incorporating interdisciplinary pedagogical frameworks including those extending to the humanities, arts and social sciences.

9 Further, van Steenbrugge and Ryve (2018) elaborate "[t]hat is, neither steering documents, teacher education programs, nor teachers' guides include detailed lesson plans, suggestions for teacher moves or teaching plans for semesters" (p. 803).
10 The 2023 *Finnish National STEM Strategy and Action Plan* explicitly refers to "STEM" and the Finnish abbreviation LUMATE, which more broadly covers the natural sciences, mathematics and technology than the formerly used abbreviation, LUMA.
11 The strategy is supported by a range of initiatives, including the National Numeracy and Mathematics Hub.

Teacher Education

"Teachers are the cornerstone to inclusive, equitable and high-quality education"
(UNESCO Institute for Statistics [UNESCO], 2023a, p. 1)

Effective preparatory teacher education (i.e., pre-service) and professional development (i.e., in-service) are crucial policy investments for student achievement (Darling-Hammond, 2000). The importance of content knowledge (i.e., teaching 'in-field'),[12] discipline-specific teacher education and teacher confidence particularly in mathematics and science, is a recurring theme. Teachers also need to be prepared to identify and address students' math anxiety (see AAMT, AMSI & AMT, 2022). Ball et al. (2008) assert that "teachers must know the subject they teach. Indeed, there may be nothing more foundational to teacher competency. … What seem most important are knowing and being able to use the mathematics required inside the work of teaching" (p. 404). High-quality, sustained, and intensive professional development for in-service teachers is equally important, demanding a blend of generic and discipline-specific programs (Garet et al., 2001). Issues regarding eligibility criteria and admissions processes for teacher education programs also receive persistent attention.

"Educational policy may benefit from … findings that point to the importance of … teacher education and professional development for high instructional quality and for student achievement in mathematics. Instructional quality was also found to be related to school climate and to student motivation in mathematics. Hence, providing first and foremost an orderly school climate, but also a climate where teachers, students and parents collectively prioritize success and learning, may create the foundations for high instructional quality and boost student motivation in mathematics"
(Gustafsson & Nilsen, 2016, p. 144)

In Sweden, a shortage of teachers has been reported (12,000 by 2035), particularly in STEM programs, a challenge shared with many comparators.[13] This is despite there being multiple pathways into teaching including the BA in Pre-School Education, BA/MA in Primary Education, BA/MA in Education, Higher Education Diploma in Vocational Education, MA/MSc in Secondary/Upper Secondary Education (Hartell & Buckley, 2022).[14] Initiatives to address Sweden's teacher shortages (and professional competence) have been undertaken by various parties, including the Royal Swedish Academy of Engineering Sciences (IVA). Their School in Time project (and Teachers, Industry, Welfare sub-project) illustrates how collaborative strategies involving industry and education could stimulate teacher supply in regional municipalities such as Norrbotten and Västerbotten (see IVA, 2022). The IVA study illustrates the importance of school-academia-industry collaborations (e.g., teacher pairs), the status of teachers, role models (for students and teachers), attractive learning environments, good working environments, and science centres.

Furthermore, STEM teacher education has been extensively explored (Bergsten & Grebholm, 2004; de Ron et al., 2022). Studies demonstrate that preliminary, or pre-service teacher education, teaching experience (i.e., number of years) and other teacher characteristics (e.g., gender, socio-economic status, prior achievement) impact instructional quality and students' achievement (Toropova et al., 2019). Johansson et al. (2023) report that "teachers' mathematics knowledge, along with their pedagogical subject knowledge, form the basis for how they respond to students' mathematical ideas, the correctness of their mathematical language …, how they implement the mathematics curriculum …, and what instructional quality they offer" (p. 2).

[12] The term 'in-field' relates to the disciplinary field of the specific teacher. In this instance, teaching 'in-field' means mathematics trained teachers teaching school mathematics. In many cases, school mathematics is taught 'out-of-field' (Marginson et al., 2013).
[13] The Dutch Technology Pact (*Techniekpact*) monitors teacher vacancies in the Netherlands, highlighting shortages of STEM teachers.
[14] Skolverket also provides a suite of professional development programs for STEM teachers covering programming, science and technology, didactics, digital tools in science, and sustainable development (Hartell & Buckley, 2021).

Norway's *Teacher Education 2025: National Strategy for Quality and Cooperation in Teacher Education* aims for:
"academically challenging and rewarding [teacher education] study programmes;
academically strong and well-organised teacher education providers;
knowledge-based and involved partners in the kindergarten and school sectors;
stable and mutually beneficial cooperation between teacher education institutions, the kindergarten sector, and the school sector" (Government of Norway, 2018, pp. 7-8)

STEM policies in several comparator countries seek to reform teacher education and elevate the status of teachers.[15] For example, building on the report, *The Teacher, the Role, and Education*[16] Norway's *Science for the Future* highlights the important role of science teachers,[17] consistent with a broader Norwegian reform agenda that increased teacher qualification requirements to a five-year master's program in 2017. This reform was supported by projects such as the Promotion of the Status and Quality of Teachers (Skagen & Elstad, 2023). Similarly, Denmark's *National Science Education Strategy* seeks to further elevate the teaching profession. It anticipates opportunities for more teachers to complete master's programs in the natural sciences and commits to "targeted and ongoing professional development of primary school teachers; … strengthened natural science professionalism in education for primary school teachers; … examination of the need for STEM-oriented modules in the pedagogical diploma programme; [and] … competence development of teachers in youth education" (Ministry of Education, 2018, p. 11-12). The Danish National Centre for Science Education (ASTRA), an independent centre affiliated with the Danish Ministry of Children and Education supported by public and private funding, plays a vital role in strengthening science teaching and learning.[18] Finland's new STEM strategy and LUMA Centres also recognize the importance of teachers, emphasizing initial preparation and in-service professional development for teachers in mathematics and science subjects and technical fields, along with resources for education developers.[19] Finland's strategy also prioritizes education research on mathematics and science teaching through the Finnish National Agency for Education. Similar teacher-focused policy solutions are evident in STEM policies of other comparators. For example, Germany's *STEM Action Plan 2.0* references the interdisciplinary research network involving school managers and teachers aimed at strengthening STEM teacher's pedagogical skills. In the United Kingdom, the *Science & Technology Framework* signals further recruitment and retention of "high-quality … schoolteachers in STEM-related subjects" (2023, p. 11).

Furthermore, issues around teacher shortages (generally, and specific to science and mathematics), 'in-field' teaching, and school climate are recurring themes globally (UNESCO, 2023a). Many STEM policies focus on recruitment, retention, and professional development of registered teachers, while others seek to fill these gaps with non-qualified persons (e.g., mentors), and/or solutions involving technology (e.g., online teachers and/or mentors). Australia's STEM strategy foreshadows "increasing teacher capacity and STEM teaching quality" (2015, p. 6). Elsewhere, minimum qualifications are specified by state certifying authorities for teacher registration, and the Australian Institute for

[15] STEM policies may lack explicit provisions concerning mathematics and science teacher's minimum qualifications (e.g., generalist/specialist bachelor, masters), their specific professional development trajectories, career paths and registration requirements. Instead, in many cases details for such regulated professions are determined by professional associations, unions, and higher education institutions rather than being dictated by formal policy instruments.

[16] See *Report to the Storting No. 11 (2008-2009).*

[17] Additional measures are outlined in other texts, and these change over time. Notable documents include the 2014 strategy, *The Teacher Promise: Team for the Knowledge School* referring to a new five-year basic teacher education program, and the 2017 strategy, *Teacher Education 2025: National Strategy for Quality and Cooperation in Teacher Education.*

[18] ASTRA shares science education knowledge, networks and collaborates internationally (e.g., European Science Events Association; EU STEM Coalition), delivers learning resources and events (e.g., ABC of Natural Sciences, teaching materials, Science Week, competitions) and undertakes capacity building projects to support and inspire science teachers (e.g., Big Bang annual teacher conference). ASTRA also undertakes research (e.g., Survey of Science Capital in Denmark).

[19] Such programs aim to enhance both disciplinary and pedagogical competence of schoolteachers, vocational teachers, and special needs teachers.

Teaching and School Leadership (AITSL) administers Australian professional standards for teachers spanning four career phases (i.e., 'graduate', 'proficient', 'highly accomplished' and 'lead'). Scotland's STEM strategy acknowledges teacher shortages, aims to attract high-quality STEM graduates into teaching, invests in a recruitment campaign, and foreshadows new routes into teaching. Complementary materials, *Education Governance: Next Steps* commit to delivering a coherent package of STEM professional development.

The United States *Raise the Bar: Lead the World* commits the federal government to "boldly support[ing] improved learning conditions by working to eliminate the teacher shortage" including "promoting better pay, working conditions, retention strategies, and professional development for teachers … strengthening and diversifying the teacher pipeline" (2023b, p. 2). The policy includes initiatives such as teacher residencies, professional learning programs, grants, and the National Partnership for Student Success program, to fortify the teaching workforce with mentors and coaches. STEM policies aim to strengthen school mathematics and science teaching by improving teacher education and in-service professional development, while launching strategies to increase the supply pipeline (including second career aspirants), reduce attrition (in part by addressing status, workload and career path concerns), and professional development for those teaching out-of-field. Furthermore, the United States National Partnership for Student Success in conjunction with AmeriCorps, aims to engage 250,000 mentors and coaches to support students learning. They also promote, through Engage Every Student, summer learning and afterschool programs. Similarly, the *Finnish National STEM Strategy and Action Plan* acknowledges that "ideas of deteriorating working conditions in teaching work do not encourage young people to seek employment in the teaching sector" (Ministry of Education and Culture, 2023, p. 13). Their strategy foreshadows investment to ensure high quality, teaching, including learner-centred and theme-based teaching methods, improved pedagogical skills and STEM competence. Furthermore, Finland's strategy supports research regarding teacher education. Policy enactment concerning is facilitated by various stakeholders. For example, the Australian Mathematical Sciences Institute makes available the MathsTalk Podcast, ICE-EM Mathematics textbook, and Calculate Website, including student modules and videos, to help teach sequences.

Curriculum

Approaches to curriculum design vary considerably between, and at times, within countries as illustrated by Priestley et al.'s (2021) report, *Curriculum Making in Europe: Policy and Practice Within and Across Diverse Countries*. Boesen et al. (2014) explain that "standards and curricula are changed over time" as "ideas about … education are affected by educational, philosophical, and political positions" (p. 72). In terms of key features, the OECD (2023c) observes that "in most countries … central and state authorities establish regulations or recommendations regarding instruction time and the curriculum. However, local authorities, schools, teachers and/or students also have varying degrees of freedom to organise instruction time or choose subjects" (p. 363). Central governments, local authorities and others also make available various extra-curricular activities including mathematics and science competitions.

Studies have explored curriculum structuring and sequencing (e.g., spiral and non-linear curriculum models) (Ireland & Mouthaan, 2020),[20] and highlighted the significance of balanced curriculum

[20] Ireland and Mouthaan (2020) elaborate that in the spiral curriculum model, "[l]earning is visualised as a spiral upwards from basic to advanced concepts, with topics being revisited at increasing levels of complexity as the spiral loops round. The process of reinforcement in learning is a key feature of the spiral curriculum. Each return visit has additional objectives and presents fresh learning opportunities" (p. 7). They also explain how alternative models such as "webs and networks put less emphasis on linear progression in a knowledge domain and the development of discrete skills, and more emphasis on 'meaning centred approaches'" where "the learners' grasp of the interconnectedness of ideas and the importance of transfer of learning between contexts is emphasised" (2020, p. 10). Consistent with other areas of mathematics education, models are contested.

incorporating mathematical proficiency with and beyond numbers (Kilpatrick et al., 2001).[21] The acquisition of mathematical conceptual understanding and procedural skill have both been emphasized. Spillane et al. (2018) elaborate, "While *procedural knowledge* centers on computation and following predetermined steps to compute answers to problems, *principled knowledge* focuses on the concepts that undergird mathematical procedures" (p. 1; emphasis added). Rittle-Johnson and Siegler (2022) assert that, when learning mathematics, "concepts and procedures are much of what children learn in the course of development, and without question, they develop them in tandem rather than independently" (p. 75).

Attention has also been given to assessment of mathematics and science learning, social inclusion and exclusion (e.g., girls, and marginalised cohorts including low socio-economic status, indigenous peoples and migrants), multilingualism and indigenous knowledge. Studies recommend that modern curriculum be rigorous yet adaptable, equipping students with mathematical and scientific reasoning (including algebraic reasoning), higher conceptual development, as well as digital and numerical skills. Education research literature discusses various trends around preparing students well for real-world applications, pathways into vocational and higher education, and employment, including through the integration of workplace learning. The impact of streaming is considered in multiple studies (i.e., arts/science; general-academic/vocational).

Sweden's national curriculum for school mathematics, science and technology is the responsibility of government, and studies have examined different aspects (Bergsten & Grebholm, 2004; Boesen et al., 2010). Prytz's 2015 presentation on *Swedish Mathematics Curricula, 1850-2014: An Overview* reports, "The fifth curriculum of *Grundskolan*, the most recent, was introduced in 2011. This time the mathematics curriculum had two parts: a *course plan* (about 3,000 words), which was together with the general parts and the other subjects, and the second part as a *separate commentary material* (a booklet, about 13,300 words). In total it comprised about 16,300 words, an all-time high" (p. 313; emphasis added). Topics (in the 2011 version) for mathematics in compulsory school grades 1-9 included number sense and the use of numbers, algebra, geometry, probability and statistics, relations and changes, and problem solving (Pryzt, 2015). According to Beosen et al. (2014), "[t]he subject mathematics is divided into five consecutive courses, A-E. Examples of content are; Course A: geometry, linear functions, exponential functions. Course B: statistics, probability, linear equation systems. Course C: power functions, geometric sums, derivatives. Course D: trigonometic equations, differential equations, integrals. Course E: Complex numbers" (p. 100). Amongst other things, Sweden's mathematics curriculum aims to ensure each pupil completing compulsory school "can use mathematical reasoning for further studies and in everyday life" (Skolverket, 2018, p. 11). It also aims to help students master mathematics, which others have defined as "possessing competencies such as problem solving, mathematical reasoning, procedural fluency and conceptual understanding" (Jäder et al., 2022, p. 1121).

Sweden's national curriculum for school science includes biology, physics and chemistry, while a further subject, technology, is available. In Years 1-3, science studies include biology, physics and chemistry topics under all core content (i.e., seasons of the year in nature; body and health; force and motion; materials and substances in our surroundings; narratives about nature and science; and methods and ways of working). Core content for Sweden's technology curriculum in Years 1-3 covers technological solutions, working methods for developing technological solutions, and technology,

[21] Kilpatrick et al.'s (2001) paper, that has received significant traction, proposes five strands of mathematical proficiencies: "Conceptual Understanding – comprehension of mathematical concepts, operations and relations; Procedural Fluency – skill in carrying out procedures flexibly, accurately, efficiently and appropriately; Strategic Competence – ability to formulate, represent, and solve mathematical problems; Adaptive Reasoning – capacity for logical thought, reflection, explanation and justification; and Productive Disposition – habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy" (p. 116). Mathematics curriculum developed by some countries (e.g., Australian Curriculum: Mathematics F-10) has adopted these 'mathematical proficiencies', and in others (e.g., Singapore Mathematics Framework), introduced similar approaches emphasizing the simultaneous development of multiple proficiencies (Groves, 2012).

man, society and the environment (Skolverket, 2018). For Years 4-6 and 7-9, core content is specified for biology, physics, chemistry and technology subjects (Table 4). For subsequent years of upper secondary school (*Gymnasium*), students study at least some common compulsory subjects (which may include mathematics), while choosing from 18 vocational and higher education preparatory programs. For example, this includes natural science, technology, building and construction, electricity and energy. Importantly, the extent to which Sweden has centrally regulated school curriculum through detailed curriculum documentation, or grants school and teachers' freedom and flexibility, has changed over time, along with shifts concerning the place of students as learners.

Table 4
Swedish Science and Technology Curriculum: Years 4-6 and 7-9

Subject	Core Content - Years 4-6	Core Content - Years 7-9
Biology	Nature and society	Nature and society
	Body and health	Body and health
	Biology and world views	Biology and world views
	Biology, its methods, and ways of working	Biology, its methods, and ways of working
Physics	Physics in nature and society	Physics in nature and society
	Physics and everyday life	Physics and everyday life
	Physics and world views	Physics and world views
	Physics, its methods and ways of working	Physics, its methods and ways of working
Chemistry	Chemistry in nature	Chemistry in nature
	Chemistry in everyday life and society	Chemistry in everyday life and society
	Chemistry and world views	Chemistry and world views
	Chemistry, its methods, and ways of working	Chemistry, its methods, and ways of working
Technology	Technological solutions	Technological solutions
	Working methods for developing technical solutions	Working methods for developing technical solutions
	Technology, man, society, and the environment	Technology, man, society, and the environment

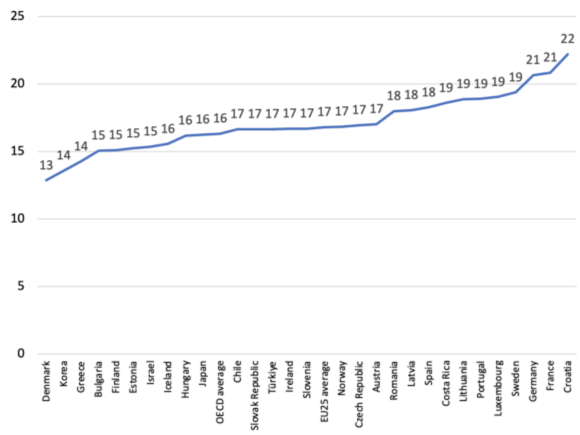
Source: Skolverket, 2018.

Furthermore, time allocated in Swedish schools to mathematics, science and laboratory learning has fluctuated over the years. Instruction time for mathematics[22] in primary education, as a proportion of total compulsory instruction time in public institutions, is higher in Sweden (19.4) than the OECD average (16.3), fourth only to Croatia, France and Germany (Figure 6). Similarly, instruction time for mathematics in Swedish general lower secondary education is comparatively high (15.3), above the OECD average (12.5), and fifth only behind Italy, Chile, Croatia and Bulgaria (Figure 7) (OECD, 2023c).[23]

[22] Hartell and Buckley (2022) have also reported instruction time for compulsory school mathematics (420/410/400 = 1,230 hours over the three stages of a total 6,890 total guaranteed hours).

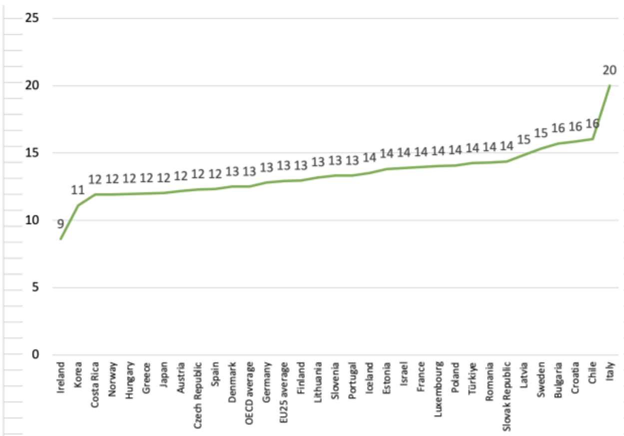
[23] Henrekson and Wennström (2022) observe reforms increasing the number of hours of mathematics instruction time (to 300) in elementary schools, arguing that "according to all measures of student performance in mathematics, the added hours have had no effect whatsoever … suggesting that the problem is the way mathematics is taught rather than the amount of time dedicated to teaching it" (pp. 151-152).

Figure 6
Instruction Time for Mathematics in Primary Education
(% of total compulsory instruction time, in public institutions)



Source: OECD, 2023c. Table D1.3. For more information, see: https://oecdch.art/0dc44e5580

Figure 7
Instruction Time for Mathematics in General Lower Secondary Education
(% of total compulsory instruction time, in public institutions)



Source: OECD, 2023c. Table D1.4. For more information, see: https://oecdch.art/02a07466ff

Instruction time for science and technology subjects is now considerably lower than for mathematics. In science, 143 hours are allocated for preschool; 193 hours for compulsory school (biology: 55; physics: 55; chemistry: 55); and 264 hours for upper secondary school (biology: 75; physics: 75; chemistry: 75), totalling 600 hours. In technology, the spread is 47 hours (preschool), 65 hours (compulsory), and 88 hours (upper secondary), totalling 200 hours. Over the years, time allocated to science laboratory learning has also decreased, and this has caused concern as it can severely limit opportunities for student's transition into STEM higher education, research and employment (Wennerberg, 2023).

The capacity of schools to enact national mathematics and science curriculum varies between municipalities (Alvunger & Wahlström, 2021), and schools. Some studies have examined multilingual mathematics education in Sweden (e.g., Norén, 2015), while others have explored programming and information communication technology (ICT) in mathematics education.[24] Österman (2017), discussing creative and algorithmic reasoning, observes the shift from "showing mathematical skills toward expressing understanding of the mathematical tasks verbally. The children are encouraged to *talk about* mathematics" (p. 521). As with several other aspects of mathematics and science education, curriculum content, goals, the balance between practical and theoretical elements, and the interconnections with other disciplines, remain contested.

STEM policies in countries with centralized control over educational curricula provide valuable perspectives on the changing landscape of mathematics, science and technology instruction in various national settings. Across Sweden's comparator countries, curriculum development, enactment and evaluation involves an array of policy actors, regulatory bodies, guiding documents, and mechanisms. The focus and breadth (e.g., science/mathematics/technology), content, duration and location of curriculum (e.g., primary/secondary/senior secondary) varies between and at times, within jurisdictions. Together with differences in participation and performance, curriculum differences are reflected in STEM policy objectives and solutions. For example, the Welsh Government's STEM policy focuses on numerical skills, building on existing curriculum reforms such

[24] Tossavainen and Faarinen (2019) report "high variation across schools [concerning] which digital tools are really used" (p. 3) to deliver content. They observe that, "If a teacher is motivated to using technology, laboratory teaching materials are replaced with virtual manipulatives, robots ..., dynamic programs to explore mathematics visually, Minecraft to work in three dimensions and so on. On the other hand, there are also classes where a teacher hardly uses other tools than a projector" (p. 3).

as the *National Literacy and Numeracy Framework* and incorporating stakeholder input for their 21st-century STEM curriculum. This is complemented by the *Curriculum and Assessment (Wales) Act 2021*, which delineates cross-curricular skills and areas of learning, including mathematics and science. Also in the United Kingdom, Scotland's strategy requires that STEM curricula align with employer needs and real-world applications and equip students with skills necessary for both professional and broader life success. To operationalize this, the strategy anticipates STEM hub networks coordinating curriculum planning across local and regional schools, ensuring relevance to labour market demands. Scotland's Curriculum for Excellence, updated in 2019, includes resources for subject initiatives (i.e., STEM, literacy and numeracy), and campaigns (e.g., Read, Write, Count and Making Maths Count). Denmark's *National Natural Science Strategy* focuses on school science and foreshadows a pilot program to assess options for technology curriculum (e.g., independent subject, or integrated through existing subjects). In the Anglosphere, Australia's STEM policy commits to standardized science and mathematics curriculum aimed at "increasing student STEM ability, engagement, participation and aspiration" (2015, p. 8).

School Features and Infrastructure

Studies reveal that key school features and infrastructure can have a profound impact on student learning, well-being and achievement. According to Barrett et al. (2019) features that "have a positive effect on pupils' academic outcomes [include]: small schools; schools locally distributed to maintain acceptable travel distances to school; small classes; low density of classroom occupancy; optimal school day length; [and] optimal scheduling of the use of spaces" (p. 10). Many studies have examined the impact of policy interventions concerning schooling structure (e.g., early years/primary/secondary), participation (i.e., access and equity), demographics (e.g., socio-economic status, migrant background status), assessments (e.g., national examinations) and student outcomes (e.g., see Woessmann, 2016; Prytz, 2021). Hanushek et al. (2013) found that "in high-income countries, increased autonomy over academic content, personnel, and budgets exerts positive effects on student achievement" (p. 227), evidenced by improved PISA results. In terms of school infrastructure, Crampton (2009) concludes that "investment in human, social, and physical capital accounts for between 55.8 and 77.2 percent of the variation in student achievement in fourth and eighth grade Reading and Mathematics" (p. 1). Other studies have found that learning improves in schools featuring good 'natural' conditions (e.g., lighting, air quality), age-appropriate learning space, ambient stimulation, and designs reflecting local climatic and cultural conditions (Barrett et al., 2019).[25] Infrastructure and support accommodations for differently abled students are clearly also important.

The Swedish education system comprises preschool (*Förskoleklass*), compulsory school (*Grundskola*), and upper secondary school (*Gymnasium*). The system also includes special schools, Sami schools, Folk high school, centers for other pedagogical activities and leisure-time (Swedish National Agency for Education, n.d.).[26] The extent to which curriculum is mandatory in compulsory school lower, middle, and upper stages from Years 1-9 (including mathematics and science) is a distinguishing feature of Sweden's school system (Hartell & Buckley, 2022). So too, national tests in Years 3, 6, 9 and upper secondary (see Hartell & Buckley, 2022).[27]

[25] In terms of Swedish school infrastructure, the absence of national guidelines for Swedish school design means there is much variation between schools, and municipalities. Rönnlund et al. (2021) identify differences relating to physical, pedagogical, and social spaces.

[26] The emergence of Sweden's education system over time has been extensively examined (e.g., Ringarp, 2016; Hansen & Gustafsson, 2019; Prytz, 2021; Henrekson & Wennström, 2022; Münch & Wieczorek, 2022; Larsson & Plesner, 2023a; 2023b).

[27] Many systems feature examples of 'teaching-to-the-test'. Österman (2017) wrote that in Sweden, "the national tests focus on conceptual and communicative skills. … and since the reputation of the school and the funding is connected to the results of these tests, they tend to direct the teaching rather strongly" (p. 522).

School Learning Resources

> "if the great contribution of artificial intelligence to mathematics education is to be through more technological, more personal and more mind-bending environments, it is certainly because it will have been designed to develop the professional skills of the teacher, and above all because it will promote the acquisition of knowledge and the development of the mathematical, scientific and cultural competencies of the learner."
> (Richard et al., 2022, p. 436)

Mathematics teaching is necessarily heavily reliant on textbooks and other school learning materials (Rezat & Strässer, 2014),[28] such as practice exercises and step-by-step solutions. Mathematics and science teachers now also use, to varying degrees, sophisticated digital technologies including laptops, scientific calculators and mobile devices (i.e., smartphones, tablets), along with massive open online courses (MOOCs) and digital libraries (Borba et al., 2016). This is in addition to the trend towards specialist school learning resources, centres and networks that implement science and mathematics education projects. Notably, this includes Finland's LUMA Centre's activities (e.g., *LUMATIKKA*, *LUMAn lumoa*, *Ulos luokasta* and StarT projects), LUMA Days, LUMA Weeks and LUMA learning communities. In Norway, the Norwegian Centre for Science Education at the University of Oslo delivers projects and resources for teachers and students, as well as research-based in-service science teacher professional development (e.g., didactic competence programs). Newton Rooms operate in multiple Nordic and other European countries, and the United States, offering inspiring STEM modules and learning environments incorporating workstations, a laboratory area, collaboration zones, and space for trained Newton Teachers.

Governments, school systems and associations also provide careers advice. For instance, Norway's Choice of Education (*Velgriktig*) and *STEMutdanning* initiatives provide website-based information about STEM education and careers. The *Finnish National STEM Strategy and Action Plan* foreshadows improved communication regarding potential STEM careers. The United States *Raise the Bar: Unlocking Career Success* initiative provides students with personalized career guidance and advice and encourages education-industry collaborations around paid work-based learning, and industry credentials for students. This initiative also supports improved pathways into college.

Policy actors, educators and industry monitor the impact of digitalization on the ways teachers teach, and the ways students learn (Borba et al., 2016, 2017; West, 2023).[29] Studies have explored the ways in which digital learning resources (i.e., tasks, objects, games, tools, curriculum software) are used in mathematics and science education (*Skolforskningsinstitutet*, 2017). Digitalization and artificial intelligence promise personalized learning[30] (Vincent-Lancrin & van der Vlies, 2020), while raising a multitude of issues. Clearly, teaching school students to use technology (including digital tools) is essential for foundational digital literacy, successful pathways through vocational and higher education, STEM (and other) industries and advanced research; particularly as technology underpins STEM-related objectives for the climate, energy, space, and security policy domains. Some countries, such as the Netherlands, have schemes to inspire primary and secondary school students to use technology (e.g., Jet-Net and Tech-Net). However, in other contexts, policy actors have raised

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[28] For a discussion on textbooks in the teaching and learning of mathematics, see Jäder et al. (2020).

[29] For example, West's report (2023) regarding the ramifications of the COVID-19 pandemic argues the crisis "exposes the ways unprecedented educational dependence on technology often resulted in unchecked exclusion, staggering inequality, inadvertent harm and the elevation of learning models that place machines and profit before people" (p. 3).

[30] Personalized learning has been defined as "an educational approach aimed at customising learning based on students' individual needs and strengths. AI applications can identify pedagogical materials and approaches adapted to the level of individual students, and make predictions, recommendations and decisions about the next steps of the learning process based on data from individual students. AI systems assist learners to master the subject at their own pace and provide teachers with suggestions on how to help them" (Vincent-Lancrin & van der Vlies, 2020, p. 7).

concerns about over-reliance on digital tools (e.g., iPads for young children). Accordingly, the ways in which digitalization impacts teaching, learning and performance of some (or all) students requires ongoing, balanced consideration.

In Sweden, as with comparator countries, textbooks remain foundational for how mathematics and science subjects are taught and learned. Sweden's schools are also typically well equipped with modern learning resources, including digital technologies. However, limitations and concerns have emerged, in addition to challenges highlighted through the COVID-19 pandemic (i.e., digital divide). For example, Viberg et al. (2023) report concerns regarding students' digital fluency, along with inadequate school technology infrastructure, slow networks, and student computers. Consistent with studies affirming the importance of teacher's digital competency, Viberg et al. (2023) consider teacher familiarity with digital tools (prior to introducing them into mathematics education) and working "with [students] to foster shared, differentiated and situated learning practices" (p. 241). Dyrvold and Bergvall (2023) point to "the importance of carefully designed teaching materials that express mathematics in a well-thought-out way, so that the quality of the teaching materials is not traded away for the sake of digital functions" (p. 1). More recently, the Swedish Government has announced a change. Responding to declining Progress in International Reading Literacy Study (PIRLS) 4th grade reading levels (2016 to 2021), the government is looking to a 'back-to-basics' refocus on traditional resources – printed textbooks (Associated Press, 2023). Rather than being prescriptive, STEM policies to some extent presume that schools provide traditional textbooks and technology-based learning resources for mathematics and science, without necessarily detailing the range of resources typically available from modern schooling systems.

Financing School Education

Clearly, total school education funding (e.g., budget/quantum, formulae) influences instruction time, class size, student-teacher ratios, teacher/management remuneration, equity, and student performance (Jackson et al., 2015; OECD, 2017a; Baker, 2018; OECD, 2023d). Notwithstanding considerable variation between comparators, governance of school funding necessarily involves relationships between leading policy actors (i.e., national/regional authorities, central/sub-central governments, municipalities/schools, principals/teachers). School financing studies acknowledge that the impact is highly contextualized, mediated by multiple factors. Most recently, school systems have been challenged by the economically constrained post-COVID environment.

> "Now more than ever, it is critical we invest in STEM education to help our students get back on track and prepare for an ever-changing world. The COVID-19 pandemic has demonstrated the importance of scientific discovery and advancement. It has also accelerated the digital and data-driven transformation of our economy and shined a spotlight on the digital divide and the importance of closing that divide. Strengthening STEM skills is critical for both short-term innovation as we overcome the impacts of COVID-19, and for preparing students to address future challenges in a complex, interconnected world"
> (Marten, 2022, para. 5)

STEM policies clearly require investment and social partner 'buy-in' to successfully realize objectives and implement identified reforms and discrete projects; however, this is frequently implicit. In a few examples, STEM policies frame a narrative and financial accounting of multiple endeavours where central government has authority to act. For example, the United States *Raise the Bar: Lead the World (Executive Summary)* spotlights[31] significant federal funding streams under six objectives. Identified

[31] This statement's broad objectives are: accelerate learning for every student; deliver a comprehensive and rigorous education for every student; eliminate the educator shortage for every school; invest in student's mental health and well-being; ensure every student has a pathway to college and a career; and provide every student with a pathway to multilingualism (Department of Education, 2023a).

under the objective, 'eliminate the teacher shortage', is funding to states and districts ($2.69 billion) for nominated projects: Supporting Effective Instruction State Grants, Teacher Quality Partnerships, Teacher and School Leader Incentive, and Augustus F. Hawkins Center of Excellence. *Raise the Bar* also references guidance for districts using Elementary and Secondary School Emergency Relief (ESSER) funds ($30 billion) to address teacher shortages. Clearly, it is reasonable to infer that the enhancement of student learning, performance and outcomes more generally in Sweden and comparator countries, including support mechanisms for all demographics will necessitate significant financial investment. Particularly in the domain of mathematics and science education, acquiring quality learning materials, state-of-the-art digital resources, specialized teacher professional development (for in-field teachers), and partnerships with industry and higher education.

Out-of-school Learning Environments

Public spaces, or out-of-school learning environments, play a significant role in nurturing science literacy (Ramey-Gassert et al., 1994). Enrichment activities through museums, science centers, planetaria and botanical gardens also contribute to formal and informal learning (Marginson et al., 2013). Museums, in particular, offer special opportunities as "spaces and places for learning" (Falk & Dierking, 2018, p. v), for improving mathematical and scientific reasoning (Pattison et al., 2018). Competitions, such as the STEM Olympics and Future League, play an important role in building engagement, curiosity, and sustainability awareness. As can discrete mathematics and science learning projects such as the extracurricular, education-industry project *MINT-Pro²Digi*, introduced by the University of Siegen in Germany. In Norway, the STEM Ecosystem project aims to facilitate interaction between schools, industry and universities to increase participation in school and higher education STEM studies. Several studies have highlighted ways in which public out-of-school learning environments can be used in mathematics and science education. For example, Kayhan Altay and Yetkin Özdemir (2022) reports that teachers use museum exhibits to teach mathematical concepts (e.g., ratio, proportion, patterns, time measurement).

In Sweden, museums have long targeted schools, both to transfer cultural heritage, and as "platforms for learning in the 21st century" (Björnberg, 2020, p. 81). Sweden's National Museum of Science and Technology (*Tekniska*) is very well patronised. Interactions with Sweden's public spaces (and their artefacts), including science and technology centers and museums, have been shown to play an important role in student's learning and development (Jakobsson & Davidsson, 2012). Universities also provide opportunities, such as the *Vetenskapens Hus* (House of Science) run by the KTH Royal Institute of Technology and Stockholm University. In addition to learning opportunities afforded through public spaces, many studies acknowledge the positive role industry can play in student's learning, for example through work experience and internships. In Sweden, this includes the *Tekniksprånget* internship program, funded by the Swedish Agency for Economic and Regional Growth.

STEM policies frequently acknowledge the significance of out-of-school learning environments such as museums, science centers and competitions. For instance, Finland's LUMA Centres act as hubs for innovative science and technology education, providing enriching learning experiences. Germany's *STEM Action Plan 2.0* highlights the role of competitions in increasing student interest in STEM, including mathematics and natural sciences competitions and Olympiads (e.g., *Informatik-Biber*). Their action plan also references the work of the Particle World Network, where the European Research Laboratory in Particle Physics (CERN) joins with German research institutes to prepare physics topics and activities for young people and their teachers. In the United States, *Raise the Bar* commits to "support the field to expand access to high-quality afterschool, summer learning, and enrichment programs through the Engage Every Student initiative", and encourage students "participating in real-world, work-based learning with skilled professionals" (Department of Education, 2023, pp. 2, 4). Australia's *National STEM School Education Strategy 2016-2026* references partnerships with industry, vocational and higher education institutions, which can extend to include such out-of-school learning opportunities. Denmark's *National Natural Science Strategy* encourages increased cooperation between schools and industry, including connections, learning materials and case studies.

Monitoring Mechanisms

Comparator countries employ a range of structures and methods to inform policy development, monitor implementation, and analyse change over time in the school, VET, higher education, and research arenas. Monitoring mechanisms may be comprehensive and mature, or more limited. They may focus on broadly monitoring multiple issues in education and training sectors and the labour market, or more specifically be deployed to monitor and evaluate implementation of particular policies, programs or reforms. They may allow country and municipality-level analysis, and/or international comparative analysis. They may be integrated into European and global datasets to greater or lesser extents. In some instances, STEM policies acknowledge that additional efforts need to be made to collect and use data from sophisticated intelligence systems. The extent to which public policy research is supported varies considerably, as does research focused on STEM education, and STEM policy. Policy and project evaluation reports may be publicly available, or not.

Sweden's comparator countries provide some illustrative examples of monitoring mechanisms. In Europe, the Netherlands *Technology Pact Monitor* reports data relating to technical education and the labour market (e.g., teacher shortages, labour demand characteristics). The *Finnish National STEM Strategy and Action Plan* includes detailed measures for monitoring, surveys and general development (e.g., relationship between student's background and mathematics and science competence and educational pathways; attractiveness of mathematics and science subjects; education research; teaching and learning environments). In terms of research and innovation, Finland's Ministerial Working Group on Competence, Education, Culture and Innovation reportedly monitors implementation of the *Updated National Roadmap for Research, Development and Innovation*, observing trends related to public and private expenditure, foreign direct investment, European Union funding through the Horizon program, internationalization and inbound international students and researchers. Denmark's *National Natural Science Strategy* anticipated new evaluation tools to monitor school science reforms, and strengthens tests in key subjects (i.e., physics/chemistry, biology and geography). ASTRA conducts a Survey of Science Capital to gain insights regarding school student's identity and STEM. Germany's *STEM Action Plan 2.0* highlights the importance of education research regarding successful STEM strategies, arguing that the "simple question" of "what makes successful [STEM] education?" is yet to be answered systematically (Ministry of Education and Research, 2022, p. 9).

In Anglophone countries, various monitoring mechanisms and research outcomes are also highlighted in STEM policies. Northern Ireland's skills policy drew on evidence in the *Northern Ireland Skills Barometer*, Department for Education's *Employer Skills Survey*, and reports of research institutes including the Institute for Public Policy Research (IPPR) (see Gunsen et al., 2018). The Welsh Government's *Science, Technology, Engineering and Mathematics (STEM) in Education and Training* Policy signals that some additional monitoring efforts will be undertaken, building on data reporting and employer surveys previously introduced (e.g., trends and projections for future STEM skills and occupations). This strategy acknowledges that additional analysis will be required "to better understand specific issues regarding the learning and teaching of STEM skills" (2016, p. 7). In East Asia, Japan's 2021 *Science, Technology and Innovation Basic Plan* identifies important reference indexes for major goals (e.g., SDG Report, the Better Life Index, GDP, and international competitiveness).

Some STEM policies explicitly reference monitoring structures (e.g., Institute for Public Policy Research), indicators (e.g., SDGs) and methods (e.g., student and employer surveys), complementing existing data collection and analytics systems more generally operationalized. Monitoring and evaluation approaches range from those that broadly track multiple aspects of STEM in school, VET and higher education sectors, and the labour market, to more targeted tools and research specifically designed for evaluating the implementation of certain STEM policies or reforms. Clearly many comparators do both. Evaluation reports and other research publications generated from these mechanisms, where publicly available, can offer insights regarding the effectiveness and progress of various policies and programs, notwithstanding challenges assigning causation.

Summary: School Science and Mathematics Policy Objectives and Solutions

STEM policy objectives and solutions relevant to school science and mathematics are summarized below (Table 5).

Table 5
School Science and Mathematics Policy Objectives and Solutions

Objectives and Solutions	Sector
Increasing interest in science and mathematics	Schools
- communication and interaction with students (including target groups)	
Increasing participation and performance in school mathematics and science	
- quality school education system and schools	
- pedagogy (mathematics, science, technology) (includes personalized support and coaching)	
- teachers (pre-service teacher education; in-service professional development; 'in-field'; recruitment and retention; school climate; shortages)	
- curriculum (mathematics, science, technology) (content, sequence, instruction time)	
- general employability skills	
- disparities (girls; under-represented; metropolitan/non-metropolitan)	
- physical and digital infrastructure (including laboratories, libraries, and internet)	
- school learning resources (mathematics, science, technology)	
- school education system investment (financing)	
- out-of-school learning environments	
- internships (work experience and VET for school students)	Industry
- education-industry collaborations	
Increasing public knowledge of science, and life-long scientific literacy and digital skills capability	Community
- communication and interaction with the public (including target groups)	
- scientific literacy and digital skills capability	
- lifelong learning	

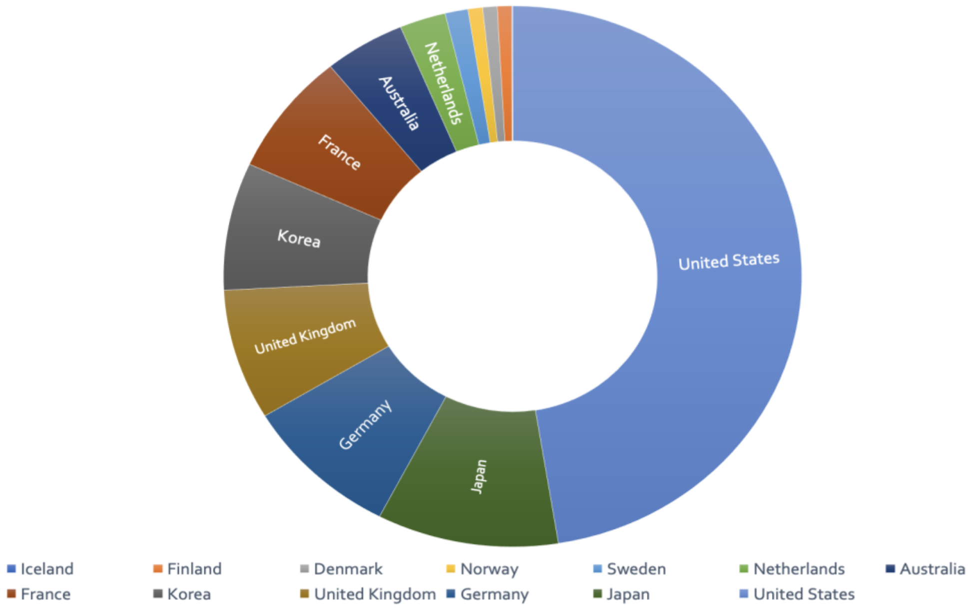
STEM VET AND HIGHER EDUCATION

Participation

Students can become further immersed in STEM disciplinary knowledge at vocational and higher education institutions. The number of students learning specific disciplines in any country is partly a function of the proportion of the population that engage in post-school study, as well as the total number of students enrolled in STEM VET and higher education programs. In Sweden, higher education participation has reached almost 50% (Gustavsson, 2022), supported by robust government student financial aid systems, high levels of public confidence (Benner & Schwaag Serger, 2023), predominantly free tuition, and the widespread distribution of institutions throughout the country. Comparatively, internationalisation of student and faculty populations lags, as Swedish universities tend to recruit domestic doctoral students and faculty (Bienenstock et al., 2014). Overall, Swedish universities perform very well, with three institutions ranking within the top 100 on the Academic Ranking of World Universities in 2022 (Karolinska Institute: 37; Uppsala University: 82; Stockholm University: 98) (ShanghaiRanking Consultancy, 2023).

In terms of total enrolments, the trend towards massification has been observed in most countries; however, in some instances, demographic changes and financial pressures have seen falling enrolments (Salamanca, 2023). In terms of higher education enrolments in 2021 (Figure 8), the data illustrate that Iceland (22,034) and other Nordic countries, Finland (305,370), Denmark (308,152), and Norway (311,592) are smaller-scale systems. Their enrollment figures are reflective of their population sizes, indicating a high per capita enrollment in higher education. Sweden (490,470) and the Netherlands (987,564) fall into this category, with Sweden showing notably higher enrollment among the Nordic countries. By contrast, Australia (1,728,866), France (2,809,289), Korea (2,908,321), and the United Kingdom (2,993,903) represent large-scale systems, at times bolstered by high international student numbers. The largest countries based on population in this sample have the largest higher education systems, including Germany (3,351,573), Japan (3,885,000), and the United States (18,159,426) (UNESCO, 2023b). Large-scale systems have an advantage in terms of the number of students in STEM fields of education.

Figure 8
Enrolment in Higher Education, All Programs (Both Sexes) (2021)



Source: UNESCO, 2023b. Note: The figure for Japan is 2020.

STEM Teaching and Learning

For VET and higher education students participating in STEM programs, the quality and relevance of teaching and learning is paramount. This includes the presence of skilled and engaging teaching faculty, as well as the availability of high-quality student learning resources, up-to-date materials, technology, and supportive learning environments. Faculty academic development, professionalization and certification of VET and higher education teaching practice has increased along with scholarship of teaching and learning (Kreber, 2002; Trigwell, 2013). Good teaching involves STEM disciplinary knowledge and expertise, and pedagogical skills necessary to engage students and adapt to diverse learning needs. Studies have identified strategies such as communities of practice (Laksov et al., 2008), team-based academic development (Bolander et al., 2022), workshops on evidence-based teaching practices, and building a shared vision (Feola et al., 2023).

Where required, STEM curriculum is updated and renewed to reflect changing societal and industry needs, and technological advances. STEM programs may involve workplace learning (i.e., internships), although this varies considerably (Freeman & Barker, 2022; Liljedhal et al., 2022). Numerous studies have explored the impact of STEM pedagogy (e.g., project-based learning, active learning, gamified learning), learning resources, and teaching faculty's attitudes and professional development on STEM participation, retention and attrition (Zhan et al., 2022).

For STEM students enrolled in engineering, natural and medical sciences, access to infrastructure such as laboratories is vitally important. In Sweden, studies have highlighted issues concerning access, which is essential for their successful learning, and transition into employment. For example, Wennerberg (2023) traces developments in one Swedish university's chemical engineering program over the last three decades, where exposure to critical curriculum elements and laboratory hours was reduced: "For students who only study compulsory organic chemistry, the reduction from 1990 to 2020 went from 115 [hours] to 10-24 [hours]" (p. 3). Such changes have consequences "partly ... poorer learning, but above all poorer skills, practice and safety-wise" (Wennerberg, 2023, p. 5). Consequences extend to employing companies, who may be required to teach recruits requisite knowledge, skills and practices on commencement.

Graduation

Supply of sufficient STEM program graduates is widely recognized as important for economic wellbeing; hence, concern regarding insufficient, fluctuating or declining participation and graduation rates and widespread acceptance of the 'leaky pipeline' metaphor (Banerjee & Graham, 2023).[32] In the following analysis, consideration is given STEM disciplines in higher education, spanning engineering, manufacturing, and construction; information and communication technologies; natural sciences, mathematics, and statistics; agriculture, forestry, fisheries and veterinary. Data for the key STEM-related discipline, health and welfare is also provided as some STEM policies broadly encompass health sciences. Students graduating from non-STEM programs are excluded from this analysis (i.e., education; arts and humanities; social sciences, journalism and information; business, administration and law; services),[33] notwithstanding the importance of this cohort.

The data show that the percentage of higher education students graduating from STEM programs varies across different regions and countries (Table 6). In the Nordic countries, the percentage of graduates in STEM is relatively high, ranging between 24-28%. Sweden and Finland lead (28%) indicating a strong inclination towards the disciplines of engineering, manufacturing, and construction, and information and communication technologies. In addition to STEM disciplines, health and welfare also constitute a significant proportion of graduates (15-21%), reflecting the Nordic region's focus on comprehensive health and welfare systems. Other European countries including Germany, France, and the Netherlands show a different pattern. Notably, Germany has the highest percentage of graduates in engineering, manufacturing, and construction (22%), contributing to a total STEM graduation rate of 35%, the highest among the comparator countries. This aligns with Germany's renowned emphasis on engineering and technical education. France and the Netherlands show more balanced distributions across STEM fields; however, have a lower STEM graduation rate compared to Germany (26% and 19% respectively). In East Asia, Korea exhibits a strong focus on engineering, manufacturing, and construction (21%), contributing to a high STEM graduation rate (30%). Among the Anglophone countries, the United States, the United Kingdom, and Australia present a more diversified distribution across STEM fields, with noticeably lower percentages in engineering, manufacturing, and construction (7-9%) relative to other comparators. Total STEM graduation rates in these countries range from 20% to 22%, indicating a moderate focus on STEM fields (Table 6).

[32] This metaphor is used to explain the trend where students leave STEM fields of education as they transition from middle to senior secondary schooling, then to higher education, with particular concerns about girls and women, and under-represented minorities.
[33] In the first instance, consideration is given to graduating students; however, it is acknowledged that variations exist between and within countries in retention rates, with some comparator countries experiencing high levels of attrition (i.e., 'drop-out' rates). High attrition rates in higher education have been attributed to issues regarding student's prior knowledge (e.g., mathematics), STEM program teaching methods, quality and social relevance of STEM programs.

Overall, the data highlights variations in higher education focus, with Germany, Korea, Sweden and Finland leaning more heavily towards engineering, manufacturing and construction (16-22%), while the United Kingdom, the United States, Germany and France (8-9%) reported higher proportions of graduates in natural sciences, mathematics and statistics. Finland, Sweden, Denmark and the United States were strong in health and welfare (20-21%). Comparator countries present varied STEM education landscapes reflecting differing cultural perceptions, societal values and historical context, emphasis on mathematics and science in earlier stages of schooling, and attractiveness of career opportunities.

Table 6
Percentage of Graduates from Higher Education Programs (Both Sexes), by Discipline (STEM, and Health and Welfare) (2021)

Region or Group	Country	Engineering, manufacturing, and construction (%)	Information and communication technologies (%)	Natural sciences, mathematics, and statistics (%)	Agriculture, forestry, fisheries and veterinary (%)	Total STEM (%)	Health and welfare (%)	Total STEM plus Health and welfare (%)
Nordic countries	Sweden	19	6	4	1	28	20	50
	Finland	16	8	4	2	28	21	51
	Denmark	12	6	6	1	24	20	45
	Norway	12	6	5	1	23	19	43
	Iceland	8	4	4	1	17	15	32
Other European	Germany	22	5	8	2	35	8	45
	France	14	4	8	2	26	13	41
	Netherlands	9	4	7	1	19	16	37
East Asia	Korea	21	5	4	1	30	16	47
Anglophone	United Kingdom	9	4	9	1	22	15	38
	Australia	8	7	5	1	21	19	40
	United States	7	5	8	1	20	20	41

Source: UNESCO, 2023b.
Note: Figures are rounded, so totals may not add up. Figures are not available for Japan.

Globally, longstanding trends regarding gender disparities persist in education and training sectors, and the workplace. In STEM, under-representation of women is evident in participation and graduation trends in traditionally male-dominated engineering, manufacturing and construction programs, as well as information and communication technology programs (UNESCO, 2023b). Gender disparities are compounded by the under-representation of minority groups in STEM fields of education (Marginson et al., 2013; Banerjee & Graham, 2023), with barriers including lack of access to quality education, societal stereotypes, and insufficient mentorship or role models. The COVID-19 pandemic noticeably exacerbated many inequities. These challenges are widely recognized. For example, in the United States, the National Science Board's *Vision 2030* report acknowledges the "case for urgency", decrying the "missing millions", referring to untapped talent pool comprising women and other groups under-represented in the country's STEM workforce (2020, pp. 6, 17). To address such issues, STEM policy interventions and educational reforms have been introduced, ranging from targeted recruitment and retention strategies, scholarship programs for under-represented groups, and efforts to foster inclusive and supportive learning environments. Germany's *STEM Action Plan 2.0* references a program that aims to retain women faculty after completion of their doctoral studies, particularly in STEM fields. There are many other examples. Additionally, there is a growing emphasis on public awareness campaigns to challenge stereotypes and encourage a more diverse range of students interested in pursuing STEM fields of education at VET and higher education level, and subsequently, throughout their careers.

Vocational Education and Training STEM Policy Provisions

STEM policies, complemented by instruments focussing more specifically on skills shortages and the labour market, have multiple objectives. This includes increasing vocational enrolments, status and quality (e.g., quality assurance, growth targets) to meet industry requirements for skilled labour in STEM and other areas. Such policies may also focus on addressing disparities, ensuring access to career counselling and vocational guidance, improving education-industry partnerships including workplace-based learning (e.g., apprenticeships, traineeships and internships) and delivering 'reskilling' and 'upskilling' programs to existing employees.

In Europe, Germany's *STEM Action Plan 2.0* acknowledges parity of esteem issues, arguing that "we must make vocational training, with its qualification offerings and qualification paths, even more attractive than other branches of education. It must prove itself to be equivalent to the university sector" (Ministry of Education and Research, 2022, pp. 15-16). Germany's plan acknowledges the role of young migrants and refugees in meeting the country's skilled labour needs (e.g., Career Orientation for Refugees). This plan also references SERENA, the computer games project that encourages young people to learn skills for renewable energies. Complementing this, Germany's *Federal Government's Skilled Labour Strategy* prioritizes up-to-date vocational training and announces a range of projects including Vocational Training Clusters 4.0 in Lignite Mining Regions, the Initiative for Excellence in VET, and a vocational training guarantee. In Finland, the Ministry of Education and Culture's *Finnish National STEM Strategy and Action Plan* explicitly acknowledges VET, stating that "[v]ocational and higher education ensure the adequacy of STEM experts in working life in different sectors of society in terms of content, quality and quantity" (2023, p. 11). The plan foreshadows VET institutions teaching mathematics and science subjects in professional programs and increasing cooperation with applied science universities and industry. In terms of participation, the plan argues for a strategic approach to decisions concerning enrolment levels in STEM disciplines at VET and higher education.

The *Technology Pact* (*Techniekpact*) in the Netherlands focuses on increasing inflow into technical education and employment, particularly women and migrants, increasing the number of companies providing apprenticeships, and public-private partnerships. Recognising persistent labour market shortages for key technical skills, the Netherlands Talent Coalition is working to increase the inbound international workforce. Iceland's *Science and Technology Policy 2020-2022* foreshadows developing a skills strategy integrating education, employment and the labour market, to better align education and labour market needs. This strategy will respond to the 2019 report, *Iceland and the Fourth Industrial Revolution*, which foresees the need for rapid change, and reflect government recognition that, for Iceland, "It is important to facilitate the hiring of foreign experts by enterprises and institutions to strengthen their knowledge base and build an international network in innovation and the knowledge industries" (2022, p. 24).

In the United Kingdom, the *Skills Strategy for Northern Ireland* stresses the urgent need to address skills shortages, particularly in STEM fields (e.g., engineering and manufacturing technologies, science and mathematics), referencing "an increasingly 'skills hungry' labour market" (Department for the Economy, 2021, p. 45). It states that "the *Skills Strategy* must place a focus on enabling more individuals to participate in post-compulsory education ... which will drive our economic recovery and improve societal wellbeing. This must be balanced, however, against the appropriate measures to ensure that existing inequalities are not exacerbated. It is vital that more individuals with low or no qualifications are effectively engaged in education and training which will provide pathways to sustainable employment" (p. 47). The policy foreshadows the introduction of enhanced employability services, local Skills Hubs, a Job Start Scheme targeting the long-term unemployed, the Skills for Live and Work program, online programs covering essential skills, and apprenticeships. The *Science Technology Engineering and Mathematics Education and Training Strategy for Scotland* similarly acknowledges labour market strategy, including STEM-focused apprenticeship programs at foundation, modern and graduate level.

Several STEM policies reference employability, generic, 21st century or transferable skills; many of which feature strongly in VET programs. These skills have been researched extensively, and definitions and applications remain contested. The OECD (2017b) highlights the ability to communicate, work in teams, lead, solve problems and self-organize. A more extensive list of emerging skills includes analytical thinking and innovation; creativity, originality and initiative; active learning and learning strategies; technology design and programming; complex problem solving; critical thinking and analysis; leadership and social influence; systems analysis and evaluation; reasoning, problem solving and ideation; emotional intelligence; and resilience, stress tolerance and flexibility (World Economic Forum, 2018). The *Future of Jobs Report 2023* argues that analytical and critical thinking are the most important skills, along with resilience, flexibility and motivation (World Economic Forum, 2023).

Higher Education STEM Policy Provisions

STEM policies concerning higher education focus generally on increasing participation in STEM programs and assuring quality teaching and learning. Strategies include robust higher education funding, quality assurance systems, and growth targets. While studies consistently acknowledge the loose coupling between fields of education and occupation outcomes, and difficulties projecting future labour market trends, STEM policies frequently aim to increase participation in STEM fields of education. Where they address the post-school STEM ecosystem, they also aim to address disparities for women and under-represented groups and increase research. Many STEM policies also foreshadow increased government-education-industry, and education-industry partnerships, including internships (i.e., work integrated learning), collaborative research, and commercialization (i.e., intellectual property development and exploitation, patents, inventions and licenses). Some STEM policies include strategic objectives around internationalisation, both of teaching and learning (i.e., international students), research (including PhD students, scholarships and post-doctoral researchers), and globally mobile faculty.

Norway's *Long-term Plan for Research and Higher Education 2023-2032* commits to high quality and accessibility in higher education, including flexibility and accessibility of Norwegian and Sami education (e.g., decentralized and online education, study centres). The plan explicitly acknowledges both tertiary and higher education, stating "society's skills needs are not met by universities and university colleges alone, and the skills policy must therefore look at the education system as a whole" (Norwegian Ministry of Education and Research, 2022, p. 71). The *Finnish National STEM Strategy and Action Plan* recognizes the role of admissions processes in choices made by secondary school students and foreshadows investment in pedagogical development in higher education mathematics and science fields. This includes increased cooperation, including co-teaching, within and between higher education institutions in Finland and internationally (e.g., joint projects, cross-teaching). LUMA Centres, representing networked science education centres based at Finland's universities, play an integral role in science teacher education, and science education research (e.g., LUMAT Science Research Forum). Iceland's *Science and Technology Policy 2020-2022* nominates revising the university funding model, increasing university funding, introducing mechanisms to assess the impact of investment in university education, and streamlining work permit processes for specialists entering from outside European Economic Area (EEA).

The *Skills Strategy for Northern Ireland* contains strategic goals centred on increasing the proportion of the population completing post-school qualifications, generally and in STEM fields. Their emphasis on fostering a culture of lifelong learning recognizes the importance of technical and professional education pathways, as well as higher education qualifications. The policy also nominates improved alignment between higher education outcomes and economic need and attracting international faculty. It anticipates developing "a 'hub' of global expertise, that empowers the emergence of innovative, globally competitive, indigenous companies, developing – and collaborating with – world-leading academic talent, and attracting [foreign direct investment] through advanced knowledge, skills, absorptive capacity and supply chains" (Government of Ireland, 2021, p. 59). Scotland's STEM policy highlights increased education-industry research partnerships facilitated through innovation centres. Finally, Germany's *STEM Action Plan 2.0* references the *Higher Education Pact 2020* through which governments will support increased participation in, and graduation from, higher education STEM programs, and improved teaching quality.

Summary: VET and Higher Education STEM Policy Objectives and Solutions

STEM policy objectives and solutions relevant to VET and higher education STEM are summarized below (Table 7).

Table 7
Vocational and Higher Education STEM Policy Objectives

Objectives and Solutions	Sector
Increasing participation and performance in VET and higher education STEM disciplines	VET and higher education
- quality VET and higher education systems and institutions	
- teaching (STEM teaching and learning pedagogy)	
- faculty (STEM lecturers/researchers) (education; institutional climate; shortages)	
- programs (pre-STEM, bridging and STEM curriculum) (content, sequence, instruction time)	
- international education provision (STEM, other)	
- general employability skills and lifelong learning	
- disparities (women; under-represented; metropolitan/non-metropolitan)	
- investment in VET and higher education systems (financing)	
- physical and digital infrastructure (laboratories, instruments and devices, supercomputers, databases, measuring instruments, libraries, museums, archives)	
- learning resources (STEM)	
- internships (work integrated learning, apprenticeships)	Industry
Facilitating economic dynamism and competitiveness by ensuring industry demand for STEM knowledge and skills are met	
- education-industry collaborations (including public-private partnerships)	
- government-education-industry collaborations	

STEM RESEARCH AND INNOVATION

Research Priorities

Research priorities of Sweden's comparator countries are explicitly reflected in *legislation*, *policies*, *strategies*, *roadmaps* and *plans*, and implicitly expressed in *budget allocations*, procurement and program *guidelines*, research funding *criteria*, and *tax subsidies*. In many instances, multiple (at times apparently conflicting) sets of research priorities exist concurrently, with shifts occurring over time as governments change, technologies advance, emergencies occur, and contexts change. Internationally, research priorities may be "mission or challenge-based; broad thematic; intermediate topic level; specific research questions; [and] systems-focused priorities" (Australian Government, 2023, p. 22). Regional and national research priorities, deeply intertwined with STEM policies and innovation objectives, play a pivotal role in shaping research and innovation ecosystems. Some focus on STEM and interdisciplinarity, while others also encompass research in the humanities, arts and social sciences disciplines. Increasingly, the importance of this spread of disciplinary knowledge is recognized, particularly as governments endeavour to address intersecting policy domains and pressing challenges.

European Union research priorities, frequently associated with significant funding schemes (e.g., Horizon Europe) include excellent science, global challenges, and European economic competitiveness (i.e., health; culture, creativity, and inclusive society; civil security for society; climate, energy, and mobility; food, bioeconomy, natural resources, agriculture, and environment), and innovation. In the Nordic countries, there is a pronounced emphasis on sustainable technology and environmental research, reflecting a longstanding commitment to ecological stewardship and renewable energy. The priorities align with broader STEM policies, which often integrate sustainability and environmental science as core components. Norway's *Long-term Plan for Research and Higher Education 2023-2032* references thematic priorities including oceans and coastal areas; health; climate, the environment and energy; enabling and industrial technologies; societal security and civil preparedness; trust and community. Iceland's *Science and Technology Policy 2020-2022* commits to increasing research and innovation on the environment, ecosystem, climate, healthcare, and well-being, in addition to the Science and Technology Policy Council's focus on Icelandic language and technology.

In other European countries, multiple research priorities are articulated in diverse policy instruments. Germany's *Future Research and Innovation Strategy: Executive Summary* nominates pressing challenges including "climate protection, resource protection, biodiversity and marine protection and the solving of global health issues through to the elimination of technological and energy dependencies and their corresponding social impacts" (Federal Government, 2023b, p. 6). The strategy prioritizes a resource-efficient circular economy, climate (i.e., protection, adjustment, food security, biodiversity), health, digital and technological sovereignty, space, and oceans (including astronautics), as well as social resilience, diversity, and cohesion. The Dutch *Strategy to Strengthen Research and Innovation Ecosystems* nominates food technology, artificial intelligence, people with chronic diseases, nanotechnology, and precision agriculture.

Similarly, in East Asian countries, particularly Japan and Korea, research priorities are heavily inclined toward advanced technology, echoing their STEM policies that emphasize technological proficiency and digital literacy. The Government of Japan's *Science, Technology and Innovation Basic Plan* of 2021 identifies themes relating to cyber-space (i.e., big data and artificial intelligence) and physical-space digital data infrastructure, cyber-physical security, autonomous driving, light and quantum technologies, smart bio-industry and agricultural technologies, energy systems, national resilience, diagnostic and treatment systems, smart logistics and deep-sea survey technology. The Government of Korea's science and technology-related tasks aim to increase national security, support supply chain commerce, and create new industry by focusing on strategic technologies. This includes semiconductors, rechargeable batteries, next-generation nuclear power, biopharmaceuticals, aerospace and ocean, hydrogen, cybersecurity, artificial intelligence, communications, advanced robots, and quantum.

In the Anglosphere, the United States, the United Kingdom, and Australia have set research priorities that reflect their economic and geopolitical positioning. The United States and the United Kingdom have prioritized research in areas such as defense, space technology, and cybersecurity. These themes are reflected in individual policy instruments. For example, the National Science Foundation's strategic plan, *Leading the World in Discovery and Innovation, STEM Talent Development and the Delivery of Benefits from Research*, identifies opportunities and grand challenges including building a sustainable future (i.e., climate and resilience, clean energy), emerging industries (i.e., manufacturing wireless technology, biotechnology, quantum science and engineering, artificial intelligence, semiconductors) and matters related to people, technology and change (i.e., interaction with technology, conflict and change, the physics of aging, non-equilibrium systems). The United States *CHIPS and Science Act of 2022* commits to investments in semiconductor research required for nanotechnology, quantum computing and AI work.

In the United Kingdom, the *Science & Technology Framework* nominates five critical technologies (i.e., artificial intelligence, engineering biology, future telecommunications, semiconductors, and quantum technologies). It commits to funding "high-risk, high-reward R&D with a core focus on identifying and funding transformational science and technology at speed" (Department for Science, Innovation & Technology, 2023, p. 18). The *Skills Strategy for Northern Ireland* highlights key strategic clusters for economic development. This includes digital/ICT/creative industries, fin-tech/financial services, life and health sciences, agri-tech, advanced manufacturing and engineering and related technologies (i.e., digital workplaces, automation, network, computer infrastructures and platform services, storage and database, security). Australia's research policies, while also focusing on technology, tend to emphasize environmental sciences and sustainable technologies, a response to its unique geographical and ecological challenges. The (draft) revised national science and research priorities include "ensuring a net zero future and protecting Australia's biodiversity; ... supporting healthy and thriving communities; ... enabling a productive and innovative economy; [and] ... building a stronger, more resilient nation" (Australian Government, 2023, p. 1). Australia's *National Research Infrastructure Roadmap* identifies research themes including resources technology and critical minerals, food and beverage, medical products, recycling and clean energy, defence, space, environment and climate, frontier technologies and modern manufacturing.

Analysis of STEM research priorities in Sweden's comparator countries reveals different approaches to addressing current and future challenges. Priorities are not only a reflection of each country's unique social and economic context but also an active driver in shaping their scientific, technological, and educational futures. The focus ranges from advanced technology in East Asia to sustainable technology and environmental research in the Nordic countries, aligning with respective STEM policies to varying degrees. In the Anglosphere, priorities reflect economic and geopolitical positioning with a strong emphasis on defense, space technology, and cybersecurity. This brief snapshot depicts a rapidly evolving field, highlighting the importance of adaptability and responsiveness to both local and global needs.

Research and Development Expenditure and Capabilities

Data on research and development expenditure and researcher demographics provides some indication of commitment and activity from a comparative perspective. It highlights significant differences in emphasis, as well as number of researchers (Table 8). In the Nordic countries, Sweden leads with research and development expenditure of 3.42% of its gross domestic product (GDP), followed closely by Finland and Denmark, both approximately 3%. These results not only reflect a strong commitment to research and innovation but also indicate a well-established research infrastructure, as seen in the high number of researchers per million inhabitants, especially in Sweden (8,131) and Finland (7,871). Notably, Iceland stands out with the highest percentage of female researchers at 45%, significantly higher than its Nordic counterparts, which range from 33% to 39%, suggesting a progressive approach towards gender equality. Comparatively, other European countries including Germany, France, and the Netherlands also show substantial investment, with Germany allocating 3.14% of its GDP. However, these countries have fewer researchers per million inhabitants compared to the Nordic region, with the Netherlands leading at 6,074. The percentage of female researchers in these countries (29-30%) suggests a need for more gender-balanced representation in research fields. In East Asia, Japan and Korea display a robust investment in research and development, particularly Korea, which leads with an impressive 4.93% of GDP. However, both countries have a noticeably lower percentage of female researchers, particularly Japan with only 18%. In the Anglophone countries, the United States and the United Kingdom exhibit strong research and development expenditures, aligning with their global aspirations in research and innovation. Overall, these figures reflect not only the financial commitment across these regions but also highlight cultural and policy differences in the inclusivity and structure of their research sectors.

Table 8
Research and Development Expenditure and Capability (2021)

Region or Group	Country	R&D expenditure as % of GDP	Researchers per million inhabitants (full time equivalent)	Female researchers (headcount) (%)
Nordic countries	**Sweden**	3.42	8,131	35
	Finland	2.99	7,871	33
	Denmark	2.81	7,708	35**
	Iceland	2.81	6,940	45
	Norway	1.94	7,228	39
Other European	**Germany**	3.14	5,536	29
	Netherlands	2.31	6,074	30
	France	2.22	5,175	30
Asia	**Korea**	4.93	9,082	22
	Japan	3.30	5,638	18
	China	2.43	1,687	--
Anglophone	**United States**	3.46	4,452***	--
	United Kingdom	2.91	4,491*	39*
	Australia	1.83**	--	--

Source: UNESCO, 2023b. Notes: * 2017 data; ** 2019 data; *** 2020 data

Despite Sweden's longstanding strengths in public and private investment, researcher capabilities, and established universities, some scholars caution against complacency in the face of growing challenges at global and national level. For example, Benner and Schwaag Serger (2023) offer a cautionary tale, arguing that the challenges for universities have changed from concerns regarding funding, academic freedom, and institutional autonomy. They argue that, "[t]he nature of the current challenges stems from the complexity, pervasiveness, severity and concurrence of problems that characterize the early 21st century: a great power struggle between the US and China which is reverberating through geopolitics around the globe; a planetary crisis caused by climate change; the retreat of democracy and advance of authoritarianism; and rising nationalism at a time when countries' fates are perhaps more intertwined than ever" (p. 14).

Research Output

Data on research output (i.e., publications and patents) provides some basis of comparability and estimation of future opportunity. In terms of patents (Table 9), Sweden, with a population of 10.49 million, demonstrates a moderate level of patent activity with 2,196 total applications and 717 grants, translating to a patent per capita ratio of 0.07. As such, it lags behind Nordic counterparts Norway (0.12 patents per capita) and Finland (0.10) but leads Denmark (0.06). In comparison, East Asian countries, particularly Korea (2.83), Japan (1.47) and China (0.49), exhibit significantly higher patent activity per capita than the Nordic countries, indicating robust systems of innovation and technological advancement. Among the Anglophone countries, the United States stands out with a patent per capita ratio of 0.98, reflecting its strong innovation ecosystem, while Australia also shows notable activity (0.66).

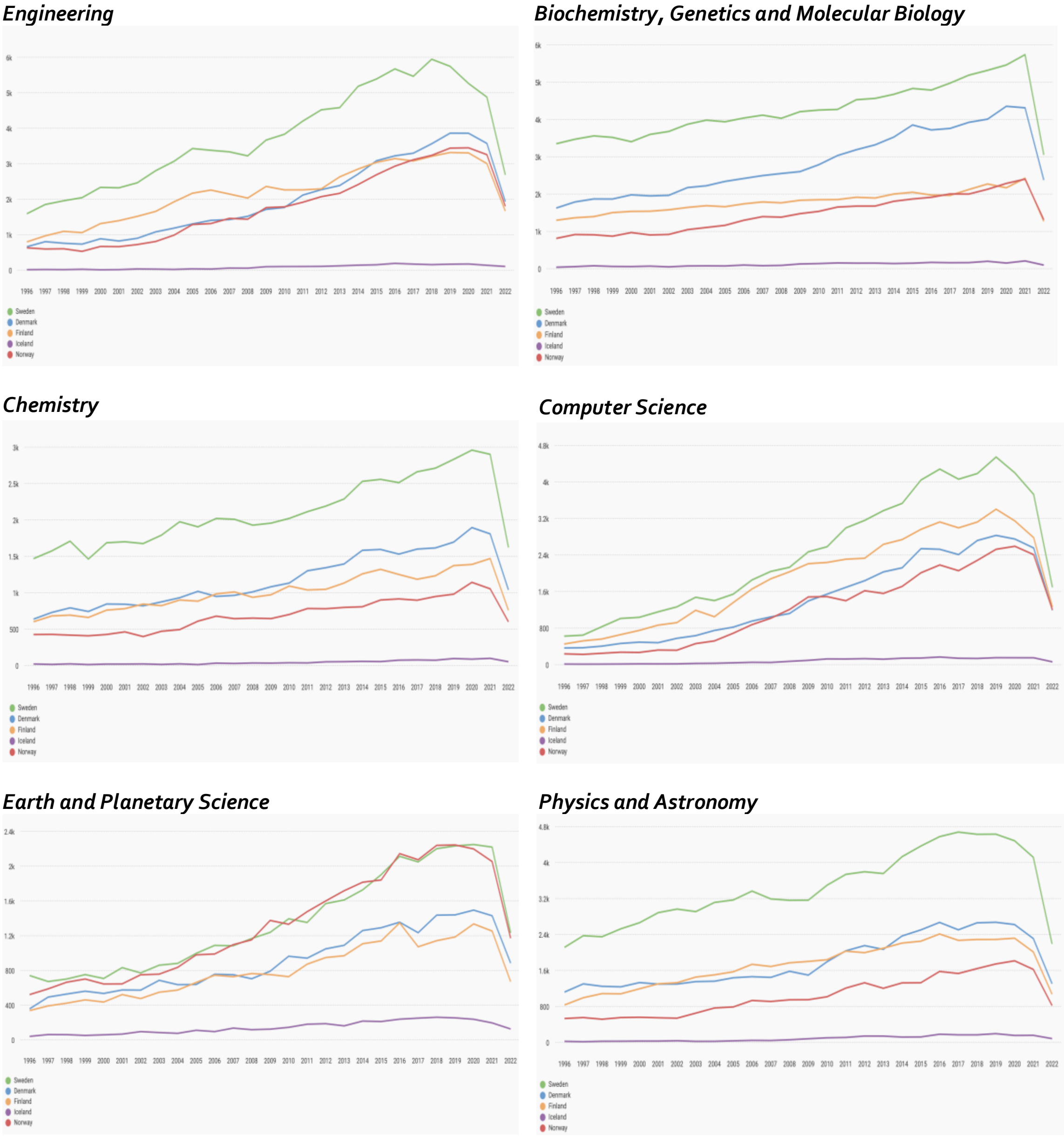
Table 9
Total Patent Applications and Grants (Residents and Non-Residents), Per Capita (2022)

Region or Group	Country	Total patent applications	Total patent grants	Population	Patents per capita
Nordic countries	Norway	1,580	650	5.46 million	0.12
	Finland	1,662	545	5.56 million	0.10
	Sweden	2,196	717	10.49 million	0.07
	Denmark	1,276	368	5.90 million	0.06
	Iceland	36	7	382,000	0.02
Other European	Germany	58,569	21,113	84.08 million	0.25
	France	14,759	15,493	67.94 million	0.23
	Netherlands	3,470	2,264	17.70 million	0.13
Asia	Korea	237,998	145,882	51.63 million	2.83
	Japan	289,200	184,372	125.13 million	1.47
	China	1,585,663	695,946	1,412.18 million	0.49
Anglophone	United States	591,473	327,307	333.23 million	0.98
	Australia	32,409	17,155	25.98 million	0.66
	United Kingdom	18,855	10,895	66.97 million	0.16

Source: World Intellectual Property Organization, 2023a; World Bank, 2023.

In terms of publications, the world leaders in output (i.e., the United States, China, United Kingdom, Germany, and Japan) have considerably more research documents than other countries across all subject categories. Overall, Sweden ranks 18th, behind several comparators for this study (i.e., France: 6th; Australia: 10th; Korea: 13th; and the Netherlands: 15th) but ahead of other Nordic countries (Denmark:23rd; Finland: 30th; Norway: 31st; Iceland: 83rd). Sweden's performance improves considerably when considered on a per capita basis. Relative to other Nordic countries in key STEM subject categories (i.e., engineering; biochemistry, genetics and molecular biology; chemistry; computer science; earth and planetary science; and physics and astronomy), Sweden outperforms with respect to the number of cited research documents, considered a proxy for quality (Figure 9). A large proportion of Sweden's publications involve international collaboration, increasing from 38% in 2000 to 68% in 2022 (Scimago Lab, 2023).

Figure 9
Cited Research Documents, Nordic Countries (1966-2022)



Source: Scimago Lab, 2023.

Innovation

The *Oslo Manual* defines a business innovation as "a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or processes and that has been introduced on the market or brought into use by the firm" (OECD & Eurostat, 2018, para. 3.9). Growing interest in innovation in the private and public sectors extends from job creation and economic growth to other economic characteristics (i.e., green, sustainable, inclusive) (Gault, 2023). Sweden has been recognised as a globally leading innovator, and this standing has been attributed to high literacy rates, political stability and meritocracy, the early introduction of intellectual property rights, and natural resources (i.e., forests, ore deposits, rivers). Furthermore, Sweden's culture of openness and trust, collaboration, free education, investment in research and development, communications infrastructure and access to capital have also contributed (Berggren & Krutmeijer, 2023, pp. 12-14). Examples of Sweden's innovative capacity are renown. Notably, the Celsius temperature scale, the centrifugal separator, engineering instrumentation and equipment (i.e., gauge blocks, ball bearings, propellers), pioneering medical treatments and equipment (e.g., Lidocaine, Omeprazole, ventilators, ultrasound, pacemaker), communications and navigation innovations (e.g., mobile broadband, Bluetooth, Skype), and the Human Protein Atlas. Sweden's innovation ecosystem is highly sophisticated, encompassing education-industry collaboration, successful entrepreneurship programs, start-up incubation and investors supported by innovation authorities (e.g., *Vinnova*, Swedish Incubators & Science Parks [SISP]), universities (and their innovation offices and legal advisers[34]), research institutes, industry and related organizations. Other key parties include learned academies, unions (e.g., *Naturvetarna*) and social partners that have longstanding experience encouraging research and innovation. For example, the Royal Swedish Academy of Engineering Sciences manages the Research2Business [R2B] platform, as well as various mentorship and knowledge transfer programs. Government and other social partners have invested in studies to explore the innovation ecosystem (e.g., *Innovation as a Driving Force* investigation), and Sweden's universities and research institutes are heavily engaged in basic and applied research, and knowledge transfer.

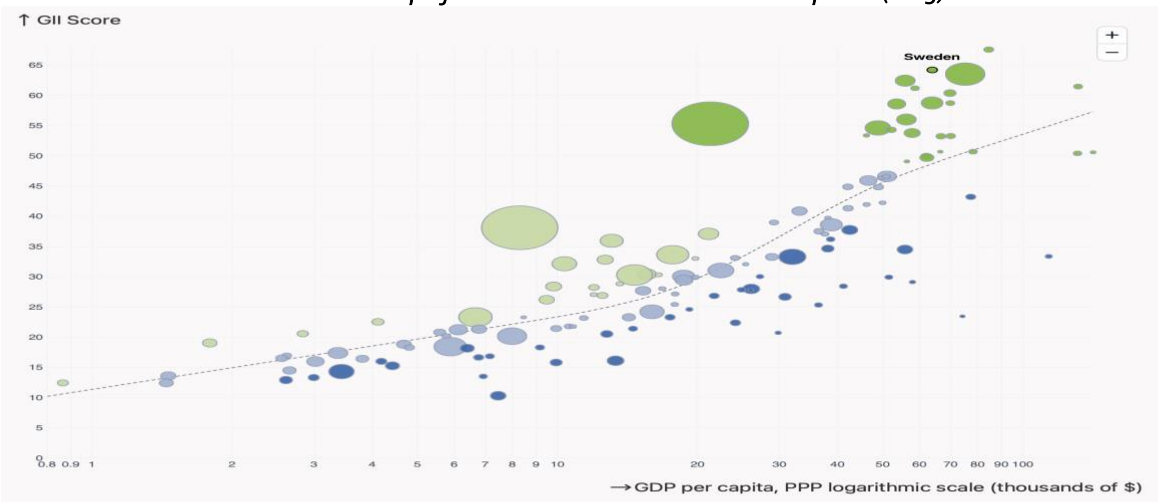
Sweden's approach to research and innovation policy has shifted over time, informed by reviews and advice (see OECD 2016; ESIR, 2017; Mazzucato, 2018; OECD, 2021), the emergence of Agenda 2030, and positioning within the European Union and globally. Sweden's research councils and agency for innovation systems each play vital roles in the nation's research and innovation ecosystem, together with industry bodies, established and start-up businesses. Arnold and Barker (2022) argue that research and innovation policy was initially characterised by delegation to the science community (and research funding councils), before a pivot to the pursuit of societal gains through applied research, industrial innovation, and economic growth (i.e., research vs innovation communities). More recently, Sweden's research and industrial innovation policy has focused more explicitly on societal challenges such as climate change and the environment, including achievement of the SDGs. Schwaag Serger and Palmberg (2022) observe "the development of new policy instruments, on new forms of cross-sectoral and cross-ministerial coordination, and on incentivizing the research system to respond more directly to societal needs" (p. 143). They also identify increasing interest in missions emphasizing "forward-looking and transformative research and innovation policy" (Schwaag Serger & Palmberg, 2022, p. 144).

Sweden continues to perform well. The *Global Innovation Index 2023* ranked Sweden second only to Switzerland, and in the high-income economy cluster ahead of the United States for the first time. Sweden performs very well relative to economic development (measured as GDP per capita). Other high performers include Switzerland, the United States, the United Kingdom, Singapore, Finland and the Netherlands (Figure 10). Sweden's ranking reflects high performance in indicators related to knowledge and technology outputs, creative outputs, business and market sophistication, human capital and research, infrastructure, and institutions. Main strengths include patents, and researchers as a proportion of the population.[35] Areas identified for improvement include entrepreneurship policies and culture (ranked 43rd), government funding/pupil, secondary (27th), pupil-teacher ratio, secondary (56th), and graduates in science and engineering (33rd) (World Intellectual Property Organization, 2023b).

[34] The Royal Swedish Academy of Engineering Sciences (n.d.) emphasizes the importance of universities having sufficient knowledge about copyright legislation, and intellectual property and contract law, to support entrepreneurship, innovation and commercialization.

[35] The landscape includes global corporate investors from Sweden (Ericsson, Volvo, Geely Sweden Holdings, Hexagon), unicorn companies in Sweden (Northvolt, Klarna, KRY) and intangible-asset intensive companies in Sweden (Atlas Copco AB, Hexagon AB, Assa Abloy AB) (see World Intellectual Property Organization, 2023b).

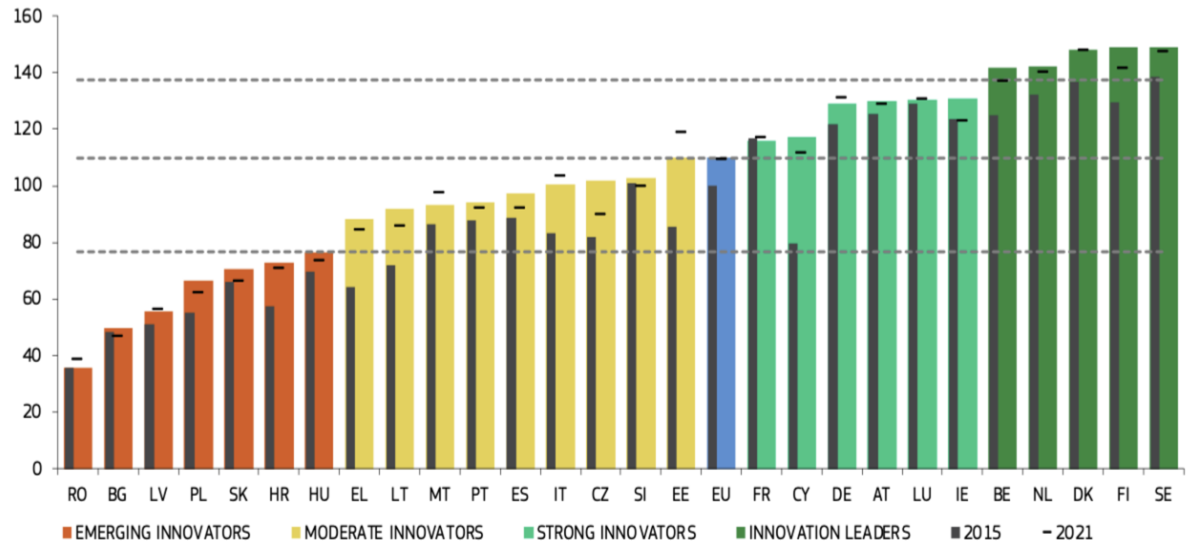
Figure 10
Innovation Overperformers Relative to Economic Development (2023)



Source: World Intellectual Property Organization, 2023b.

Consistent with this, the *European Innovation Scoreboard* has repeatedly ranked Sweden first in innovation, attesting to the country's strengths in public-private and international scientific co-publication, and employment of ICT specialists (Figure 11). At the same time, performance data suggests capacity for improvement in terms of the Swedish Government's support for business research and development, and non-research and development innovation expenditures (European Commission, 2022).

Figure 11
Performance of European Union Member States' Innovation Systems (2015-2022)



Source: European Commission, 2022.

Research and Innovation Policies

"Innovation support and transfer, coupled with a bolstering of the start-up scene, constitute key tasks of research and innovation policy. Future viability and innovative strength hinge on how well ideas, knowledge and technology are transferred between science, business, politics and use in society. … We want to strengthen transfer, allowing research results to be turned into innovations and safeguarding our natural basis of life, prosperity and quality of life."
(Federal Government, 2023b, p. 4)

Research and innovation policies reflect strategic priorities for public and private research and development ecosystems, shaped by unique national contexts. The capacity of government to direct and incentivise vitally important research is such that most countries maintain multiple related pieces of *legislation*, *budgetary allocations*, *policies*, *programs*, and *texts* governing these matters.[36] Research and innovation policy objectives seek to advance scientific knowledge and understanding, stimulate economic growth and national competitiveness, address societal challenges, educate the current and future workforce, support national security and sovereignty, while enhancing quality of life. STEM specific objectives include, amongst others, increasing participation and performance in higher education STEM disciplines (including higher degrees by research), increasing STEM research capability, activity, output and excellence, increasing research innovation and commercialization, and addressing grand challenges. Key strategies include increasing investment in research and development activity, engaging faculty and researchers across higher education institutions, research institutes and industry, addressing disparities, and boosting research and development effort (i.e., basic and applied research, STEM, interdisciplinarity).

Furthermore, research and innovation policies prioritize enhancing physical and digital infrastructure, including local, national and international research facilities (e.g., CERN European Centre for High Energy Physics; the European Synchrotron Radiation Facility in France; and Sweden's European Spallation Source). These facilities are typically managed by international consortium of scientific interests. Policies are also oriented towards fostering internationalization through global science, networks, and researcher mobility (i.e., migration policy[37] and support), and promoting open science/data. They also highlight public and private investment in the commercialization of research (e.g., early stage and growth capital), strengthening education-industry collaboration, supporting the incubation of start-ups (and scale-ups), implementing supportive schemes (e.g., tax incentives or credits, grants and loans), and attending to governing legislation and regulation. Several recent policies also acknowledge the role that scientific advice, research and innovation necessarily play in a post-COVID world (see Government of Iceland, 2022).

The following section provides some illustrative material from comparator country's research and innovation policies, broadly capturing the strategic priorities across various national contexts. It is intentionally generalized, with references provided to support further consideration where required. In the Nordic countries, governments have ambitious research and innovation policies focusing on high-quality scientific research with societal benefits. The Danish Government's commitment to excellence, coupled with societal application, exemplifies this approach. The *Objectives for Danish Research and Innovation* anticipates that "all Danish research will be of a high international quality" with "the top level … reach[ing] the same echelons of greatness as those at a Nobel-level of achievement" (Ministry of Higher Education and Science, 2018, p. 5). At the same time, the Danish Government commits to ensuring that research benefits society. Strategies include establishing a Danish Nobel pact, strengthening the quality of research across the scientific spectrum, revising basic university funding models and career pathways, investing in research infrastructure (e.g., WindScanner.dk; DIGHUMLAB; the national research vessel, DANA; museums and libraries), improving technology transfer and international cooperation, improved tax conditions, and increasing research regarding the public sector (e.g., education and daycare). The *Danish Roadmap for Research Infrastructure 2020* complements these objectives, emphasizing infrastructure for the

[36] For example, Germany's suite of policies includes *Research and Innovation that Benefit the People: The High-Tech Strategy 2025*, the *Open Access Strategy 2020* of the applied research organization, *Fraunhofer-Gesellschaft*, and the *Science Platform Sustainability 2030*. As such, a detailed country-specific reading of STEM and research and innovation policy could readily extend to related texts.

[37] In this report, issues related to migration policy concern inbound international students (e.g., post-study work rights; pathways to permanent residency), inbound researchers (higher education institutions, research institutes, industry) and skilled labour (e.g., visa application and renewal processing periods; visa eligibility conditions; visa permit timeframes; employment/salary conditions; and pathways to permanent residence).

primary areas of energy, climate and the environment; biotech, health and life sciences; materials and nanotechnologies; physics and the universe; and social sciences and humanities.

Finland's *Updated National Roadmap for Research, Development and Innovation* foreshadows increased research and development expenditure (to 4% of GDP), along with strategies to enhance competence levels, improve Finland's capacity to attract and retain international researchers, and secure additional private investment in research and development. The roadmap highlights the connection between research funding models and researcher capacity levels, observing the impact of "fragmentation and unpredictability of research funding … on the attractiveness of a research career" (Government of Finland, 2021, p. 5). The roadmap foreshadows increasing the number of international students, with higher levels of post-graduation employment within the domestic labour market. It also foreshadows partnerships between the Academy of Finland and Business Finland to drive strategic cooperation between education, research and industry partners. Norway's *Long-term Plan for Research and Higher Education 2023-2032* commits to enhancing competitiveness and innovation capacity by increasing public and private research and development, facilitating green and digital transition initiatives through European collaborations (e.g., Horizon Europe, European Research Area), and increasing digitalization. The plan also provides for transformational 'missions' that explore solutions for technological and societal problems facing society (e.g., sustainable feed for farmed fish and livestock; and including more children in education, employment and society). It also spotlights quality and accessibility in research, academic freedom, open science, and infrastructure:

> "Generally speaking, good quality of research depends on a well-functioning R&D system. This means good interaction between researcher-initiated and user-initiated research, between basic and applied research, innovation and commercialisation, and between different institutions engaged in research, such as universities, university colleges, institutes, health trusts and regional health authorities, and enterprises. It is important that these institutions have a long-term perspective, strategic priorities, modern infrastructure and the required expertise. Also, researchers must be guaranteed good working conditions and sufficient operating funds for their research activities."
> (Norwegian Ministry of Education and Research, 2022, p. 22)

Iceland's *Science and Technology Policy 2020-2022* commits to increasing research and innovation on priority areas (e.g., environmental issues), supporting open access for research data generated with public funds, developing an innovation dashboard, and increasing dissemination of science to counteract misinformation and fake news. They also commit to examining taxation incentives and grant systems for research and development. The complementary policy, *Iceland, the Land of Innovation*, outlines the country's vision for innovation, while the *Policy on Scientific Research in Health Sciences* specifically focuses on one STEM area.

In other European countries such as Germany, France, and the Netherlands, research and innovation policies are similarly comprehensive but with distinct focuses and suites of related texts. For example, the *Second French Plan for Open Science*, effective until 2024, builds on the *Digital Republic Act*, *2016* and *Research Programming Law, 2020*. It aims to build open science as a common, shared practice amongst research and innovation sectors in Europe and internationally. The plan obligates recipients of public funded to disseminate research (e.g., data, source code and research methods), and foreshadows the development of a national platform for research data (*Recherche Data Gouv*) and performance assessments around open science. It also supports multilingualism and research regarding automatic translation tools. These policies and initiatives are also supported by European structures, networks and programs, ensuring a collaborative and strategic approach to research and innovation within the continent. Notable examples include the Horizon Europe research framework, the international strategy referred to as the Global Approach to Research and Innovation.

> "Science, technology and innovation are not only generating the driving force of economic growth, but they are also becoming the lifeblood of the nation from the viewpoint of overcoming social issues … In particular, the scope of science, technology and innovation is rapidly expanding as a key means of demonstrating national power, boosting our presence in the international community, and realizing comprehensive security in the face of an increasingly severe security environment" (Government of Japan, 2022, p. 3)

In East Asia, centralized, planned approaches are evident in research and innovation policies. Japan's 2021 *Science, Technology and Innovation Basic Plan*, their 6th plan, envisages science, technology and innovation transforming the country into a sustainable, resilient society while acknowledging threats, geopolitical shifts, and environmental issues. It also aims to develop frontiers of knowledge through a convergence of natural sciences, the humanities and social sciences (HASS), strengthen research capabilities, and ensure education and human resource development sufficient to realize happiness and wellbeing. These objectives require expansion of STEM-specific focus to include interdisciplinarity and non-STEM, HASS disciplines, together with strengthened financial investment, public-private partnerships, and strong governance through the Council for Science, Technology, and Innovation.[38] Complementing this, the Government of Japan's *Integrated Innovation Strategy 2022* reiterates the fundamental pillars of Japan's science, technology and innovation policy: "enhancement of [the] knowledge base (research capabilities) and human resource development; creation of [the] innovation ecosystem; [and] strategic promotion of advanced science and technology" (2022, p. 1). Japan's policy recommits to public investment in research and development, supporting start-ups, foreshadows revitalising rural areas through digital and other leading-edge technologies, while emphasizing the importance of "investment in knowledge and people" (2022, p. 5). The Korean *Government R&D Innovation Plan* aims to improve the role of small and medium enterprises in the research and development ecosystem and prioritizes optimizing the 'user-oriented' environment for research. Korea's plan envisages increasing technological support for small and medium-sized industry, the hidden champions of economic development, through reforming research investment, planning and management approaches, and academia-industry partnerships. The Government of Korea's *Framework Act on Science and Technology* supports plan success, stipulating clearly the various provisions for master plans for science and technology.[39]

In the Anglophone countries, research and innovation policies are largely driven by aspirations of global scientific and technological leadership. Strategies of the United States and the United Kingdom in particular, reflect their ambition to maintain a competitive edge in global science and technology. These nations emphasize public and private investment in research, fostering international collaborations, and enhancing the commercialization of research findings. In the United States, research and innovation policy has long celebrated the country's global dominance in

[38] Importantly, this plan reflects a significant change to the *Basic Act on Science, Technology and Innovation* in 2021 to incorporate the humanities and social sciences. As such, the *Science, Technology and Innovation Basic Plan* now "contributes to the comprehensive understanding of human beings and society and to the solutions of problems, not only through the promotion of science and technology, but also through the convergence of knowledge that is the fusion of knowledge in the humanities and social sciences and knowledge in the natural sciences that creates social value" (2021, p. 8).

[39] This includes "objectives for developing science and technology[;] … industry and human resources relating to scientific and technological innovation[;] … increasing investments[;] … promoting science and technology research and development[;] … fostering cooperative and convergent research and development; securing future promising technologies; cultivating capabilities … by enterprises, educational institutions, and science- and technology-related institutions and organisations; disseminating … outcomes, fostering technology transfer and commercialization, and invigorating technology-based business start-ups; … advancing basic research; … training human resources in science and technology …; advancing local science and technology; fostering the internationalization of science and technology; … encouraging the creation, protection, and utilization of science and technology-based intellectual property and building infrastructure thereof" (Government of Korea, 2014, pp. 3-4).

innovation and commercialization (see Wessner & Wolff, 2012). Recent notable federal innovation legislation, the *Creating Helpful Incentives to Produce Semiconductors and Science Act of 2022 (*CHIPS and Science Act of 2022*)* aims to reinforce the United States' leadership in scientific research and development, particularly in emerging technologies such as nanotechnology, clean energy, quantum computing, and artificial intelligence. This legislation seeks not only to enhance the nation's manufacturing capabilities in these cutting-edge fields but also to establish regional high-tech hubs and strengthen the STEM workforce. Provisions are made for advanced manufacturing tax credits to encourage private investment, government funding schemes (e.g., CHIPS for America International Technology Security and Innovation Fund), the National Semiconductor Technology Center, and programs. The package includes investment in STEM programs, workforce development, and research through the National Science Foundation, Department of Energy, Economic Development Administration, National Institute of Standards and Technology, and National Aeronautics and Space Administration (i.e., Moon to Mars Program Office). Complementary legislation, executive orders, policies and strategies focus on different aspects of the innovation ecosystem (e.g., energy, space).[40]

The United Kingdom's *Science & Technology Framework* features global positioning and international partnerships, including long-term research and infrastructure collaborations, deployment of the Science and Innovation Network, a systematic approach to addressing security risks associated with such collaboration and investment, increased commercialisation and knowledge exchange, and recruitment internationally (e.g., high-skilled visa system). This policy also foreshadows increased public and private investment in physical and digital research and innovation infrastructure, and strategies to encourage increased innovation in the public sector. Complementing this, the *UK Research and Development Roadmap* elaborates government ambitions for world-class research (including 'moonshots'), investment in research and development (public/private; domestic/international), people, global collaboration, as well as world-leading infrastructure and institutions. The research roadmap also aims to strengthen "the interactions between discovery research, applied research, innovation, commercialization and deployment" (United Kingdom Government, 2020, p. 6). The *UK Innovation Strategy* commits to increasing public investment in research and development, reducing complexity regarding finance, review migration policy to attract and retain globally mobile skilled labour, and foster business-led research projects exploring new technologies.

Australia's *National Research Infrastructure Roadmap* complements the *Digital Economy Strategy*, *Action Plan for Critical Technologies* and *National Climate Resilience and Adaptation Strategy*. It leverages various government programs, such as the University Research Commercialization Scheme. The roadmap supports large-scale observations and integrated datasets, physical collections and biobanking, and software analysis tools and platforms. It anticipates improved investment in digital, biology, environmental and climate infrastructure, along with support for collections (i.e., biobanks, natural science collections, museums, botanical gardens and longitudinal records). Complementing this, *Australia 2030 Prosperity through Innovation* prioritizes stimulating high-growth firms and improving productivity (e.g., tax incentives; market development grants), catalysing innovation (e.g., flexible regulatory environment; open data), increasing research translation and commercialization, as well as ambitious national missions. This strategy involves improving skilled migration and enhancing Australia as a business investment destination.

Across Sweden's comparator countries, a common theme is the recognition of research and innovation as vital drivers of economic growth, national security, and societal progress, necessitating ongoing investment and strategic policymaking in these areas. Objectives around fostering scientific

[40] For example, the *National Innovation Pathway of the United States* focuses on clean energy and supports the implementation of the 2021 *Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. It is enacted through multiple executive orders and aims to facilitate investment in and deployment of emerging technologies (e.g., offshore wind, carbon capture and storage, advanced nuclear power), supported by legislation, regulations and financial incentives.

excellence, facilitating knowledge commercialization and transfer, and addressing both local and global challenges are consistent throughout this sample of research and innovation policies. Distinct regional trends also emerge among nominated comparators. Nordic countries including Sweden, Denmark, Finland, Norway, and Iceland prioritize high-quality scientific research with societal benefits, focusing on enhancing research quality, revising funding models, and investing in infrastructure, particularly to address climate change and sustainability. Other European nations, including Germany, France, and the Netherlands, emphasize technological innovation and open science, with strategies ranging from fostering scientific advancements to collaborative research efforts and European integration. The Anglophone countries, namely the United States, United Kingdom, and Australia, aim for global scientific and technological leadership, involving public-private investments, international collaborations, and strategies for digital transformation and national missions. In East Asia, Japan and Korea focus on transforming society through strategic technology, with Japan advancing its basic plan and Korea boosting research and development growth and nurturing strategic technologies. Each comparator's approach reflects its unique priorities, blending national ambitions with global trends in science and technology. Research and innovation policy objectives and solutions are summarized below (Table 10).

Summary: STEM Research and Innovation Policy Objectives and Solutions

Table 10
Research and Innovation Policy Objectives and Solutions

Objectives and Solutions	Sector
Increasing participation and performance in higher education STEM disciplines - entrepreneurship programs - higher degrees by research - faculty (STEM research supervisors) (institutional climate; shortages) - disparities (women; under-represented; metropolitan/non-metropolitan) - higher education systems financing (investment) - internships (PhD students)	Higher education
Increasing STEM research effort and excellence including national priorities, grand challenges and societal issues - research and development financing: public and private (investment) - faculty/researchers (higher education and research institutes and industry) (recruitment, retention/precarity, grant funding) - disparities (women; under-represented; metropolitan/non-metropolitan) - research and development effort (basic and applied; STEM; interdisciplinarity; HASS) - United Nations Sustainable Development Goals for 2016-2030 - physical and digital infrastructure (laboratories, instruments and devices, supercomputers, databases, measuring instruments, libraries, museums, archives) (international, European, national, local) - internationalisation (global science; European and international networks; mobility) - promotion and dissemination of research insights (science communication; open science)	Research and innovation (higher education and industry)
Increasing research, innovation and commercialization - research and development investment (financing) - innovation and commercialization investment (public and private capital) - intellectual property generation and exploitation (including patents) - start-up incubation - innovation offices - public-private-partnerships and industry-academia collaboration	Industry
- tax incentives - legislation and regulation	Government

STEM LABOUR MARKET

Across Sweden's comparator countries, there is longstanding recognition of the importance of STEM knowledge, skills and capabilities to meet industry needs, achieve the SDGs and societal wellbeing, and progress broader climate, energy, space, and security policy objectives. Regional initiatives such as the European Green Deal also highlight the importance of STEM for successful green and digital transition, particularly in the energy, transport, construction and agriculture sectors (Muench, 2022). At the same time, globally, labour markets are experiencing shortages in many STEM fields, including critical shortages in STEM trades, technical occupations, professional groups, and management positions. In Europe, shortages have been reported for healthcare occupations (i.e., nurses and generalist medical practitioners), software professionals, construction, and engineering. Trades experiencing widespread shortages include plumbers and pipe fitters, welders and flame cutters, carpenters and joiners, concreters, and mechanics (McGrath, 2021). STEM skilled workers have become increasingly mobile within and across borders, and many countries have changed migration and industrial relations policies to address shortages while retaining existing employees. This issue impacts Sweden's advanced comparator countries recruiting skilled labour globally, as well as others with mobile STEM workforce (e.g., other European Union countries, China, India, the Middle East).

In many European and Anglophone comparator countries, labour market shortages have been attributed to a growing 'STEM crisis' where the demand for skilled professionals and workers outpaces the supply. The situation is compounded by educational systems struggling to keep pace with industry demands, rapidly changing technological landscapes, and competing priorities for constrained public finances. In East Asian countries including Japan and South Korea, similar challenges prevail, often intensified by demographic shifts such as aging populations and declining birth rates, leading to a reduced pool of young people entering STEM fields. Nordic countries, despite their strong educational systems, are not immune to this trend, facing challenges in meeting the specialized needs of their technologically advanced, modern and innovation-driven economies. Even in countries and municipalities with low rates of unemployment (and under-employment), options for addressing STEM shortages have proved problematic, either at country-level, or at regional level (e.g., non-metropolitan areas).

Similar challenges have been observed in Sweden, with its labour force of 5.26 million in 2022. From 2010 to 2022, employment in the human health and social work industry sector steadily grew, rising from 700,000 in 2010 to 762,000 in 2022, reflecting growing demand. Similarly, employment in the education industry sector grew over this period (from 488,000 to 578,000). In contrast, industry sectors including manufacturing and transportation and storage experienced a decline in employment numbers, indicating possible shifts in economic focus or efficiencies gained through technology and automation. The professional, scientific, and technical activities sector shows notable growth, increasing from 349,000 in 2010 to 532,000 in 2022 (OECD, 2023e), suggesting an expansion in knowledge-based industries and the importance of scientific and technical expertise in Sweden's economy (Table 11).

Table 11
Employment Activity, Sweden (2010-2022)

Employment activity	2010	2014	2018	2022
Human health and social work activities	700,000	733,000	755,000	762,000
Education	488,000	532,000	579,000	578,000
Wholesale and retail trade, repair of motor vehicles and motorcycles	553,000	556,000	575,000	536,000
Professional, scientific and technical activities	349,000	402,000	439,000	532,000
Manufacturing	545,000	509,000	511,000	493,000
Public administration and defence, compulsory social security	271,000	307,000	367,000	421,000
Construction	302,000	317,000	349,000	336,000
Information and communication	175,000	197,000	239,000	315,000
Administrative support service activities	197,000	218,000	240,000	246,000
Transportation and storage	243,000	245,000	248,000	206,000
Accommodation and food service activities	154,000	159,000	173,000	159,000
Arts, entertainment and recreation	112,000	121,000	135,000	122,000
Financial and insurance activities	96,000	98,000	96,000	121,000
Real estate activities	64,000	75,000	78,000	97,000
Agriculture, hunting and forestry	95,000	94,000	88,000	97,000
Electricity, gas, steam and air conditioning supply	23,000	25,000	28,000	34,000
Water supply, sewerage, waste management and remediation	19,000	21,000	25,000	25,000
Mining and quarrying	9,000	10,000	10,000	12,000
Other service activities	115,000	124,000	137,000	129,000
Total – All activities	4,524,000	4,772,000	5,097,000	5,256,000

Source: OECD, 2023e.

At the same time, labour market shortages have been observed in Sweden, ranging from engineering (Ahlström, 2022), to STEM trades required by the construction and installation sector. This sector forecasts demand for "broadened basic knowledge, specialist competence and boundary crossers … [or] the ability and skill to break down 'information silos' and integrate systems" (Electrical Contractors Association, n.d., p. 15). Further, the Swedish Higher Education Authority (2021) has predicted shortages of higher education graduates in key STEM fields by 2035, including engineering, forestry, science and health (i.e., general, specialist, nurses, physiotherapists, chemists), and education (i.e., school and VET teachers). Labour market shortages signify a critical need for strategic alignment between STEM policy instruments, industry requirements, workforce development initiatives, and related policies (i.e., migration and industrial relations).

STEM STRUCTURES AND ENVIRONMENTS

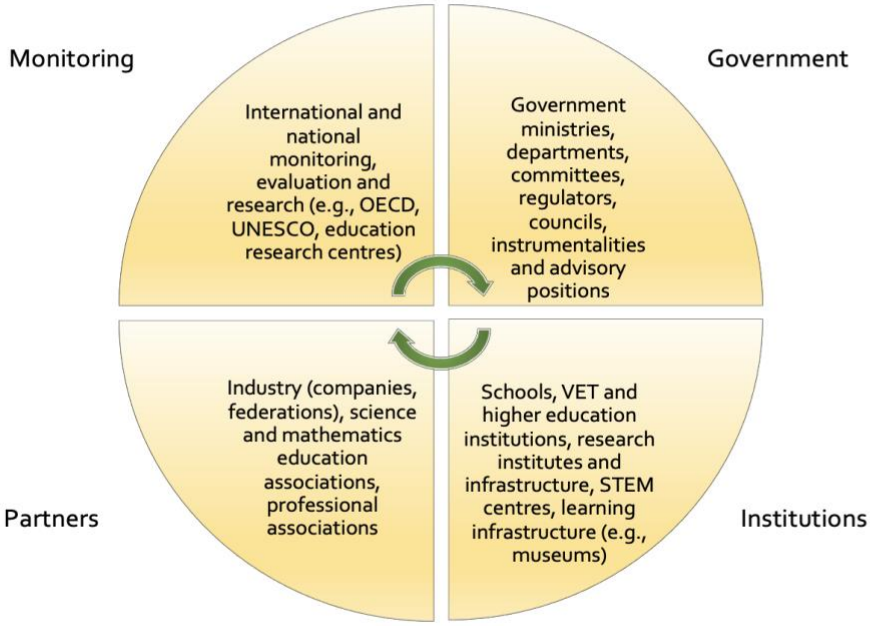
The STEM landscape encompasses a shifting suite of public, private, philanthropic and community-oriented structures, institutions or frameworks for the governance, facilitation, operation and evaluation of different aspects of school, vocational and higher education STEM, and STEM research and innovation (Appendices 1-3). STEM structures frequently reflect government's political and policy priorities (see Freeman, 2023) in the respective context, or environment. The configuration of government STEM policy bureaucracy and the extent to which it steers, enables, delegates and demands accountability varies widely between and within countries. Sweden's comparator countries have multiple high-level science and technology committees that advise governments and ministers (e.g., Presidents Council of Advisors on Science and Technology in the United States, and the United Kingdom's Council for Science and Technology). The structure of government ministries responsible for various aspects of STEM (and STEM-related) legislation, policy instruments, budget allocations and portfolios differ significantly, illustrated by differences between Denmark's Ministry of Children and Education, Japan's Ministry of Education, Culture, Sports and Technology (MEXT), and Germany's Federal Ministry of Education and Research. In many instances, multiple ministries have responsibility for STEM and research and innovation policy domains, requiring cross-ministerial co-ordination. Government departments with responsibility for STEM, research and innovation also vary considerably between countries, with cross-departmental co-ordination expected.

Authorities with specific responsibility for STEM policy instruments exist in some jurisdictions (e.g., United States Office of Science and Technology Policy). Related mechanisms include diverse governmental authorities and committees (e.g., Finnish National Agency for Education) and funding councils. Many countries (and some regions) appoint high-level advisory positions (e.g., chief scientists, science and technology advisors) (e.g., see European Science Advisors Forum). International and national monitoring structures and data collection regimes are also in place to track progress in education, training and research, including the OECD, UNESCO, the European Commission's Eurydice Network, and Australian Council for Educational Research (ACER). In many instances, these intelligence systems and collections are yet to achieve sufficient coverage and/or inter-operability. STEM-oriented evaluation authorities include Korea's KISTEP (Korea Institute of S&T Evaluation and Planning), amongst many others.

Diverse organizational structures at national and municipal levels support STEM education and research in addition to schools, VET and higher education institutions, research institutions and infrastructure (e.g., European Spallation Source) and related organizations (e.g., museums, libraries, planetaria). For instance, Finland's LUMA Centre network enables pedagogical innovation and excellence in mathematics, science, and technology. The Danish National Centre for Science Education (ASTRA) plays a vital role, while in the United States, the Comprehensive Center Network (CCNetwork) works collaboratively to meet educational needs, partly through the distribution of effective teaching and learning materials. In many instances, such centres are networked nationally and internationally.

Science and mathematics education associations are also well established in comparator countries, including the National Science Teacher Association (NSTA) in the United States, and Australian Science Teachers Association (ASTA). At the regional level, initiatives such as the European Schoolnet and the EU STEM Coalition exemplify collaborative approaches to STEM education across different countries. These initiatives involve task forces for developing STEM policies, platforms, and programs (e.g., EU STEM Coalition) that play vital roles in connecting stakeholders and fostering policy borrowing. The Science on Stage Europe network, with STEM teachers and trainers across 35 countries, is another example, guided by National Steering Committees.

Figure 12
STEM Structures: Components and Environments



In Sweden, responsibilities for STEM most notably reside under the Ministry of Education and Research. Key government authorities for education include the Swedish National Agency for Education, Swedish Schools Inspectorate, the Swedish Research Council, and Swedish Institute for Educational Research. In terms of VET, higher education and research, authorities include the Swedish National Agency for Higher Vocational Education, Swedish Higher Education Authority, and Swedish Council for Higher Education. These structures change from time to time. Sweden's learned academies in STEM fields are longstanding (e.g., Royal Swedish Academy of Engineering Sciences, Royal Swedish Academy of Sciences), as are professional associations including the Swedish Association of Professional Scientists, and Engineers of Sweden. Many higher education institutions specialize in STEM fields of education and research (e.g., KTH Royal Institute of Technology, Chalmers University of Technology, Uppsala University), while some centres and departments focus on various aspects of STEM (e.g., National Centre for Mathematics Education at Gothenburg University). Some lead in education fields (e.g., Stockholm University, Karolinska Institute, Linkoping University). Industry is integrally involved (e.g., Confederation of Swedish Enterprise), and Sweden is connected with various European STEM and STEM-related initiatives. As such, Sweden's STEM ecosystem is longstanding, well regarded, and complex. Several examples are explored through brief case studies in the following section.

STEM CASE STUDIES

STEM-UP, Region Skåne, Sweden

The competence supply, especially within STEM, is crucial for the future development, transition, and growth of trade and industry throughout the country including Skåne, Sweden's most southern region. The challenge, however, is that while demand is currently high (with prediction to future increases) the supply of competence in the field is simultaneously decreasing. Currently, there is no cohesive support structure or active competence supply strategy in place in the region to address the challenge, and actions previously conducted to target it have been fragmented and insufficient.

To meet the competence supply challenge within STEM, Region Skåne, the liable and evident actor for regional development in the region, has applied for EU-financing to conduct an extensive, far-reaching project. The project period is three years, and the budget is estimated to 38m SEK. Together with target groups, stakeholders, and co-creators from the public and private sphere, the project aims to strengthen and gather the regional business promotion system as well as relevant development within education systems. The goal is to create a sustainable regional support structure that will safeguard the competence supply within STEM – the most prioritized competence supply challenge of the future.

The activities will be created and performed together with the target groups and stakeholders, through an iterative process of co-creation, to eschew the risk of the result of the project becoming a desktop product. The activities will target a broad range of groups – from actions to increase the interest and knowledge within STEM-subjects among children, to increasing the ability among businesses to attract new STEM-talents and maintaining existing ones. The anticipated change of the current state after the project is finalized, is that there will be a sustainable regional support structure in place, that will enable strategic competence supply within STEM in Skåne (Rundgren & Szczepankiewicz, 2023).

European Spallation Source (ESS) and MAX IV Synchrotron Laboratory, Lund, Sweden

The European Spallation Source (ESS), a multi-disciplinary European Research Infrastructure Consortium (ERIC), is located in Lund, Sweden. A powerful neutron source, the ESS will enable scientific discovery on materials, energy, health and the environment, and address important societal challenges, with an expected construction completion timescale by 2027. Data generated is managed and analyzed at the Data Management and Software Centre (DMSC) in Copenhagen, Denmark. As one of the largest new science and technology infrastructure projects, the ESS encompasses the most powerful linear proton accelerator built to date, a sophisticated target wheel, cutting-edge neutron instruments, and comprehensive laboratories. A pan-European initiative with 13 member countries, including hosts Sweden and Denmark, the ESS will welcome thousands of guest researchers annually, primarily from European universities and institutes, as well as industry, marking it as a hub of scientific discovery and collaboration in Europe. Currently employing over 550, from over 60 nationalities, involving over 100 institutions. The success of the ESS depends on the capacity to recruit and retain management, science and engineering, specialist, support and technical services workers from Sweden and internationally.

The MAX IV Laboratory in Sweden, a successor to MAX-lab (1987-2015), has been operational since 2016. It currently provides 16 beamlines for advanced X-ray techniques, aiding diverse scientific studies of structure, chemistry and electronic properties. Its unique accelerator complex, including a 1.5 and 3 GeV storage ring, enables the generation of intense X-ray light, marking it as the first fourth-generation light source worldwide, enhancing experimental techniques based on exceptional brightness and coherence. As a highly specialized scientific research facility based in Sweden, MAX IV employs over 300 people from 35 nationalities, primarily in research and development, IT system development and management, as well as manufacturing repair and technical services. The laboratory annually hosts over 1400 academic and industrial users, primarily from Sweden and other European countries. This figure is expected to double in coming years. During the period 2020-2023, approximately 70% of positions required a university degree (25% PhD), with STEM expertise in physics, chemistry, engineering, computer science, biology and mathematics (Reisdal, 2023). The successful operation of such important research facilities (both ESS and MAX IV) requires the ability to assure competence supply, to recruit technical services and high-level, STEM-qualified employees, including Swedish and international talent.

Red Glead Discovery, Lund

Red Glead Discovery is a leading Swedish early drug discovery company, specializing in medicinal, computational and peptide chemistry, fragment screening, assays and screening, NMR spectroscopy, ADME and analysis. The company invests heavily in research and innovation, and engages actively in academia-industry collaborations, conducting projects to address societal challenges, and publishing research papers. Key managers contribute directly to Lund University and Lund Technical University as adjunct professors, engaging in discussions regarding higher education STEM curriculum (e.g., chemistry, biomedicine, engineering). The company also hosts students, illustrating the various ways in which science-based companies can partner with universities for STEM education and knowledge production. Launched in 2011, Red Glead Discovery now has over 55 employees, predominantly in laboratory or science-based positions (60% PhD), representing 16 native languages. With over 220 clients globally, the ability to recruit and retain STEM-qualified employees is vitally important.

Small Animal Hospital, Lund (*Lunds Djursjukhus*)

Lunds Djursjukhus, a small animal hospital based in Lund, opened in 1983. Since 2019, the hospital has operated under Evidensia, which manages 85 units throughout Sweden, with over 2,000 employees. The hospital specializes in small animals, providing a policlinic (i.e., examination, ultrasound, x-ray, sampling), a laboratory capable of biomedical analysis, a care unit (i.e., post-operative care, infection units, oxygen cage), operation capabilities (i.e., surgery, endoscopy and CT), a dental department, physiotherapy, and store. The animal hospital in Lund employs over 70 staff including licensed nurses and veterinarians and provides specialist support for over 30,000 dogs and cats (Båghammar & Tornberg, 2023). As with other cases, STEM competency supply issues extend to veterinary sciences and related staff, constraining businesses such as this small animal hospital.

Kiruna Mine, Lapland, Sweden

LKAB's Kiruna mine stands as the largest underground iron ore mine and an important element of Sweden's industrial framework. This company extends its focus to enabling STEM competencies through educational and recruitment initiatives. Partnering with entities such as the Teknikens Hus Foundation and the Luleå University of Technology, LKAB proactively engages in cultivating community and workforce skills. These partnerships represent a proactive recruitment strategy to attract skilled professionals and tradespeople, including much-needed STEM teachers, to support the region's growth and LKAB’s strategic shift towards rare earth elements. Initiatives such as the LKAB Academy and MindDig.com not only upgrade workforce skills in areas such as automation and environmental management but also enhance the region's appeal, drawing on the company expertise. LKAB illustrates challenges of large companies based in Sweden’s regions securing advanced STEM capabilities in diverse STEM fields from geology to environmental sciences.

Slussen, Sweden

The Slussen Project in Stockholm is an ambitious urban redevelopment initiative aimed at modernizing and enhancing a critical junction that serves as the centre of the city's transit network. This extensive venture is not only an illustration of advanced engineering but also a multidisciplinary collaboration designed to create a safer and more engaging environment for the public. As a hub that facilitates the flow of different modes of transportation, Slussen's transformation will secure drinking water for two million people, while integrating increased spaces for public transport, and fostering cultural and social activities with the construction of new office buildings, parks, and cultural spaces. The full range of STEM knowledge and skills are crucial to this project, as it requires the expertise of professionals and tradespeople in fields such as civil and environmental engineering, urban planning, water resource management, and architectural design to ensure that the new infrastructure is resilient, functional, and sustainable for future generations. The experiences of partners involved in important infrastructure projects such as Slusson illustrate the immediate ramifications of STEM skills shortages, highlighting the urgency to find short and long-term policy solutions.

Yrkeshögskolan, Sweden (Higher Vocational Education)

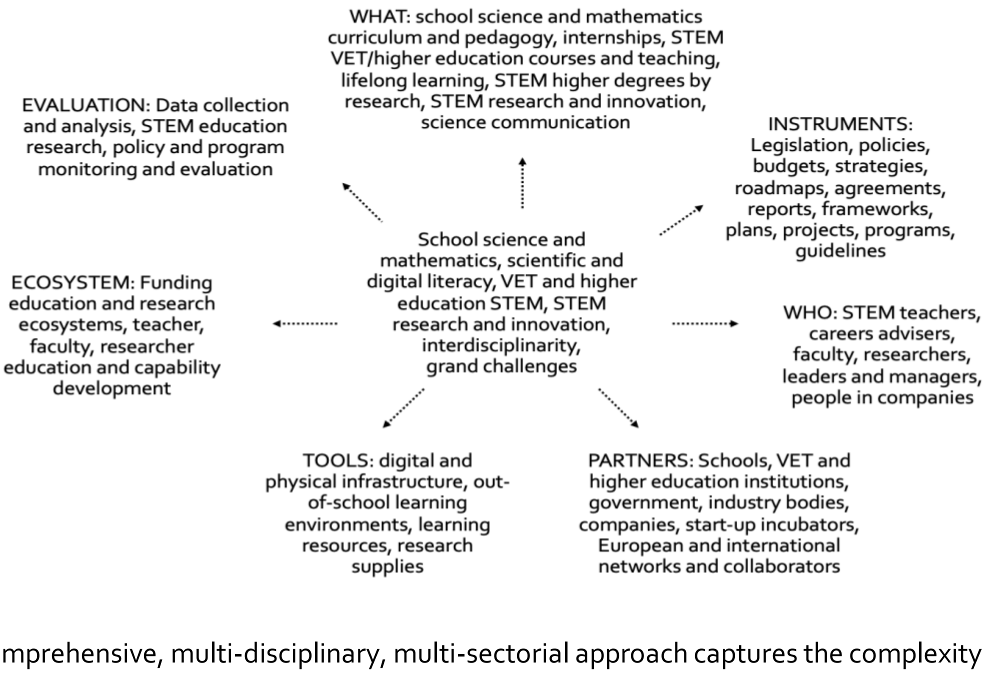
In Sweden, higher vocational education (HVE) integrates practical and theoretical learning in a wide range of up-skilling and re-skilling programs. Since its inception in 2009, MYH have grown to become one of the leading private higher vocational education entities in Sweden, offering programs across a spectrum of disciplines including construction, infrastructure, automation, technology, and business finance. Developed in close collaboration with Sweden's installation and construction industries, MYH's programs are delivered nationwide through its partner locations. They have developed and run a 'MYH Anywhere' concept that combines online lectures with region-specific content, and partnerships with local businesses for hands-on group training. This approach allows MYH to deliver programs to small cities and rural areas throughout Sweden. Committed to inclusivity, MYH actively pursues gender equity goals, facilitates an internship program (LIA), and collaborates with industry to develop innovative short courses for engineers, project managers and site managers. In doing so, MYH is contributing significantly to addressing STEM skills shortages and bespoke industry needs in Sweden.

CONCLUSION

This report, commissioned by the Confederation of Swedish Enterprise, offers a comprehensive analysis of STEM policies introduced by 12 of Sweden's comparator countries, including fellow Nordic states and others from Europe (the Netherlands, Germany, and France), the Anglosphere (United States, United Kingdom, and Australia), and East Asia (Japan and South Korea). The report illustrates the breadth and integration of multiple components addressed through comparator's STEM, research and innovation policies. Ranging from school science and mathematics (including curriculum, pedagogy, and internships), STEM VET and higher education programs and teaching, lifelong learning, STEM higher degrees by research, and STEM research, innovation and commercialization. Extending to genuine interdisciplinarity, and as required, encompassing the humanities, arts, and social sciences disciplines.

Clearly, STEM policy development will be of direct interest to Sweden's social partners and stakeholders, including government, industry bodies, education institutions (i.e., schools, VET and higher education institutions), research institutes and facilities, established companies and start-ups. This study anticipates that the Swedish Government will use a range of policy instruments to achieve STEM objectives, including policies and budget allocations for discrete projects, along with support for education-industry collaboration and broader education reforms. The report also highlights the tools necessary to achieve STEM policy objectives, including quality and accessible digital and physical infrastructure, out-of-school learning environments, learning resources, and research supplies. This ecosystem, prioritized and incentivized by government and social partners through STEM policy, can be purposefully evaluated to inform continuous improvement and progressive achievement of established and emerging STEM policy objectives.

Figure 13
STEM Policy: Integrated Components



A comprehensive, multi-disciplinary, multi-sectorial approach captures the complexity of an effective STEM ecosystem, recognizing the interplay between educational content, the roles of various social partners, the strategies and tools implemented, and the importance of collaboration. At its core, STEM policy with ambitions for quality, equitable schooling, VET and higher education, to achieve societal, national and global challenges at intersecting policy domains, while addressing dynamic industry demands, and achieving innovation and competitiveness.

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APPENDICES

Appendix 1 –
Study Sample – STEM, and Research and Innovation Policies, Select Comparator Countries

Region	Country	Title	Type	Length	Publisher	Date
Nordic countries	Finland	*Finnish National STEM Strategy and Action Plan. Experts in Natural Sciences, Technology and Mathematics in Support of Society's Welfare and Growth* (includes national *LUMA Strategy 2030*, and action plan)	Strategy and Action Plan	27 pages	Ministry of Education and Culture	2023
		Updated National Roadmap for Research, Development and Innovation	Roadmap	15 pages	Ministry of Education and Culture	2021
	Norway	*Science for the Future: Strategy for Strengthening Mathematics, Science and Technology (MST) 2010-2014*	Strategy	48 pages	Norwegian Ministry of Education and Research	2010
		Long-term Plan for Research and Higher Education 2023-2032	White Paper	107 pages	Norwegian Ministry of Education and Research	2022
	Denmark	*National Science Education Strategy*	Strategy	28 pages	Ministry of Education	2018
		Danish Roadmap for Research Infrastructure 2020	Roadmap	62 pages	Danish Agency for Higher Education and Science	2021
		Denmark – Ready to Seize Future Opportunities. The Government's Objectives for Danish Research and Innovation	Objectives	12 pages	Ministry of Higher Education and Science	2018
	Iceland	*Science and Technology Policy 2020-2022*	Policy	62 pages	Prime Minister's Office, Government of Iceland	2020
Other European countries	The Netherlands	*National Technology Pact 2020*	Pact	Website	Ministry of Economic Affairs and Climate	2013 (then updated)
		Strategy to Strengthen Research and Innovation Ecosystems	Strategy	14 pages	Ministry of Economic Affairs and Climate Policy	2021
	Germany	*STEM Action Plan 2.0 (MINT-Aktionsplan 2.0)*	Plan	26 pages	Ministry of Education and Research	2022
		National Skills Strategy	Strategy	23 pages	Federal Ministries of Education and Research, Labour and Social Affairs, and Economic Affairs and Energy	2019
		Federal Government's Skilled Labour Strategy	Strategy	38 pages	Federal Ministry of Labour and Social Affairs	2022
		Future Research and Innovation Strategy: Executive Summary	Strategy	15 pages	Federal Government	2023
	France	*Second National Plan for Open Science 2021-2024*	Plan	28 pages	Minister for Higher Education, Research and Innovation	2021
		Roadmap for French National Research Infrastructure	Roadmap	35 pages	French Government	2016
Anglosphere countries	United States	*Charting a Course for Success: America's Strategy for STEM Education*	Report	48 pages	Committee on STEM Education of the National Science & Technology Council	2018
		Raise the Bar: STEM Excellence for All Students	Executive summary	8 pages	Department of Education	2023
		Research and innovation legislation (e.g., *America COMPETES Act*, *CHIPS and Science Act of 2022*)	Legislation	Various	United States Government	Various
	United Kingdom	*Strengthening the UK's Position as a Global Science and Technology Superpower*	Letter and Annex	3 pages	Council for Science and Technology	2021
		Science & Technology Framework: Taking a Systems Approach to UK Science & Technology	Framework	19 pages	Department for Science, Innovation & Technology	2023
		UK Research and Development Roadmap	Roadmap	60 pages	United Kingdom Government	2020

		UK Innovation Strategy. Leading the Future by Creating it	Strategy	116 pages	Department for Business, Energy and Industrial Strategy	2021
	Scotland	*Science Technology Engineering Mathematics Education and Training Strategy for Scotland*	Strategy	56 pages	Scottish Government	2017
	Wales	*Science, Technology, Engineering and Mathematics (STEM) in Education and Training. A Delivery Plan for Wales*	Plan	35 pages	Welsh Government	2016
	Northern Ireland	*Skills Strategy for Northern Ireland. Skills for a 10x Economy*	Strategy	104 pages	Department for the Economy	2021
	Australia	*National STEM School Education Strategy 2016-2026*	Strategy	12 pages	Education Council	2015
		Australia 2030. Prosperity through Innovation. A Plan for Australia to Thrive in the Global Innovation Race	Plan	125 pages	Australian Government	2017
		National Research Infrastructure Roadmap	Roadmap	111 pages	Australian Government	2021
Asia	Japan	*6th Science, Technology and Innovation Basic Plan*	Plan	93 pages	Government of Japan	2021
		Integrated Innovation Strategy 2022	Strategy	34 pages	Government of Japan	2022
	South Korea	Framework Act on Science and Technology	Act	34 pages	Government of Korea	2014
		Science and Technology Basic Plan	Plan	n/a	Ministry of Science and ICT	2022
		Basic Framework for Regional Innovation based on Science and Technology Policy	Framework	14 pages	Ministry of Science and ICT	2017
		Government R&D Innovation Plan	Plan	9 pages	Government of Korea	n/a

Note: Further analysis can be undertaken by including additional documents from the numerous STEM-relevant texts available in each country.

Appendix 2 – Scoping the Research Literature

Extensive analysis of Sweden's school, vocational and higher education systems is available from Swedish experts. For example, mathematics research literature and materials are published by:

- the Swedish Institute for Educational Research
- the Swedish Society for Research in Mathematics Education
- the Royal Swedish Academy of Sciences (National Committee for Mathematics)
- the Swedish Association for Mathematics Didactic Research
- the National Centre for Mathematics Education at Gothenburg University
- other universities, associations, and organisations (Appendix 1 and 2).

According to the Academic Ranking of World Universities (ARWU), Swedish universities particularly strong in mathematics include KTH Royal Institute of Technology, Chalmers University of Technology, Uppsala University, the University of Gothenburg, Lund University, Linkoping University, and Stockholm University.

In education, leading Swedish universities include Stockholm University, Karolinska Institute, Linkoping University, Umea University, the University of Gothenburg, and Uppsala University.

Appendix 3
Select Mathematics and Science Education Associations, by Region

Region	Mathematics Education Association	Website*
International	International Group for the Psychology of Mathematics Education (IGPME)	https://www.igpme.org/
	International Society for Design and Development in Education (ISDDE)	https://www.isdde.org
	EU STEM Coalition	https://www.stemcoalition.eu
	International Council of Associations for Science Education (ICASE)	https://www.icaseonline.net
	The Association for Science Teacher Education (ASTE)	https://theaste.org
Nordic countries	Nordic Society for Research in Mathematics Education (NoRMA)	https://sites.google.com/view/norme/home
	The Swedish Society for Research in Mathematics Education (SMDF)	https://www.smdf.se/
	The Royal Swedish Academy of Sciences – National Committee for Mathematics	http://nationalkommitten.se
	Danish Society for Research in Mathematics Education (MADIF)	
	Finnish Mathematics and Science Education Research Association	http://www.protsv.fi/mlseura/eng/
	The Icelandic Mathematical Society	https://www.stae.is/isf/en
Other European	European Society for Research in Mathematics Education (ERME)	http://erme.site
	German Society for Research in Mathematics Education (GDM)	
	Science on Stage Germany	https://www.science-on-stage.eu/germany
	Association pour la Recherche en Didactique des Mathématiques (ARDM)	http://www.ardm.eu/
	Dutch Association of Mathematics Teachers (NVvW)	https://www.nvvw.nl/
Anglophone	The British Society for Research into Learning Mathematics (BSRLM)	https://www.bsrlm.org.uk/
	Association for Science Education (ASE)	https://www.ase.org.uk
	American Educational Research Association (AERA) Special Interest Group on Research in Mathematics Education (SIG-RME)	https://www.aera.net/SIG087/Research-in-Mathematics-Education
	National Science Teacher Association (NSTA)	https://www.nsta.org
	Mathematical Association of America (MAA)	https://www.maa.org/
	Canadian Mathematics Education Study Group (CMESG)	https://www.cmesg.org/
	Australian Science Teachers Association (ASTA)	https://asta.edu.au
Asia	Japan Society for Mathematical Education (JSME)	https://www.sme.or.jp/en/
	Korean Society of Mathematical Education (KSME)	http://www.ksme.info/eng/index.asp
	Chinese Mathematical Society (CMS)	https://www.cms.org.cn/en/

Appendix 4

Policy Intervention Evaluation – Select Clearinghouses and Databases

Region	Education Intervention Research Organisation	Website*
International	Organisation for Economic Cooperation and Development (OECD)	https://www.oecd.org/
	United Nations Educational, Scientific and Cultural Organisation (UNESCO)	https://en.unesco.org/
Europe	European Commission's Eurydice Network	https://eacea.ec.europa.eu/national-policies/eurydice/home_en
	European Schoolnet	http://www.eun.org/
	The Evidence Informed Policy and Practice in Education in Europe (EIPPEE)	http://www.eippee.eu/
	German Institute for International Educational Research (DIPF)	https://www.dipf.de/en
Anglophone	What Works Clearinghouse (WWC)	https://ies.ed.gov/ncee/wwc/
	ERIC (Education Resources Information Center), United States Department of Education	https://eric.ed.gov/
	Australian Council for Educational Research	https://www.acer.org/
	Center for the Study of Mathematics Curriculum (CSMC)	http://www.mathcurriculumcenter.org/
Asia	National Institute of Educational Policy Research (NIEPR) in Japan	http://www.nier.go.jp/English/index.html
	Korean Educational Development Institute (KEDI)	https://www.kedi.re.kr/khome/main/main.do

Navigating the Future

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