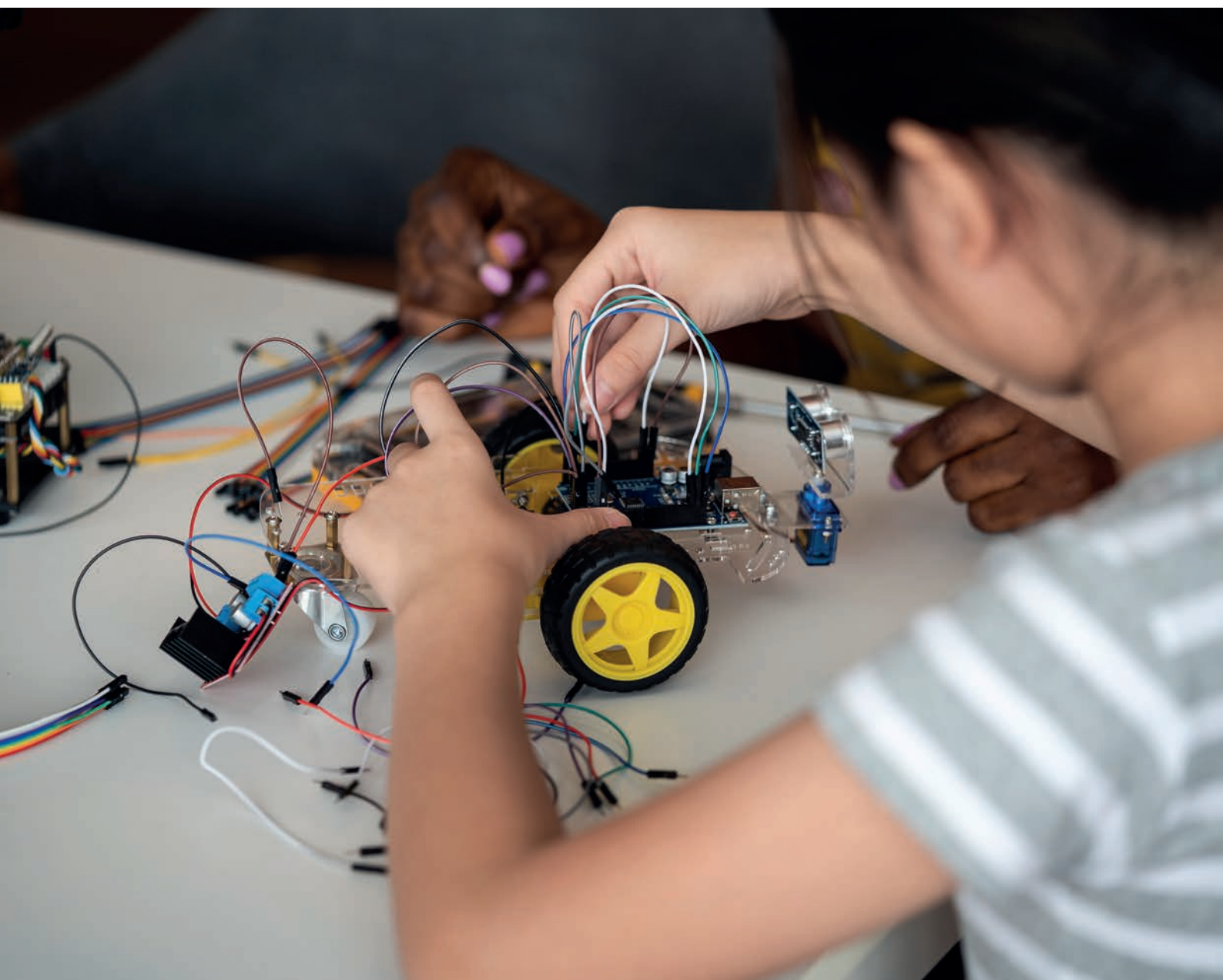


Policies for Developing Advanced STEM Skills in Higher Education



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Foreword

Advanced skills in science, technology, engineering and mathematics, referred to in this report as STEM, combine disciplinary, interdisciplinary, transversal and professional competence and develop cumulatively across education, research, employment and continued learning. Opportunities to develop, demonstrate, use and renew these skills are unequally distributed. Apparent shortages may result not only from a lack of graduates but may also arise from barriers to entering and completing STEM education, limited opportunities to progress to advanced levels, or difficulties in the recognition and effective use of these skills. The global picture is highly nuanced.

The report is intended primarily for those involved in the design, implementation, monitoring and evaluation of a joined-up strategy for the development and effective use of advanced STEM skills. These are policymakers, higher education leaders, practitioners and other key stakeholders. Many policies examined in this report are also relevant to STEM education more broadly as the development of advanced STEM skills is cumulative: access to strong foundations, high-quality teaching, progression, research and professional experience is necessary before advanced competence can be developed and demonstrated.

This report was prepared as part of the OECD project “Supporting effective implementation of the STEM Education Strategic Plan: the promotion of STEM in higher education”, undertaken with financial support from the European Union’s Erasmus+ programme. It draws on comparative data analysis, a review of research and policy literature, desk-based analysis of policy and institutional initiatives, and structured mutual learning involving policymakers, higher education practitioners and other experts. The analysis was refined through exchanges with participating countries and jurisdictions and review of the examples and interpretations included in the report. Further information on the project and methodology is provided in Chapter 1 and Annex A.

The report presents a framework to diagnose five interconnected bottlenecks: entry into STEM higher education; persistence and completion; progression to advanced levels; career entry and effective skills use; and skills renewal across working life. It examines four policy priorities and sets out common questions to support diagnosis, guide the selection and sequencing of policy instruments, and allocate responsibilities. It concludes with eight areas for policy action.

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Abbreviations and acronyms

Abbreviation/acronym	Full description
ADA	Algorithms Think Differently
AI	Artificial intelligence
BK21 FOUR	Brain Korea 21: Fostering Outstanding Universities for Research (fourth phase)
CAD	Canadian dollar
InES Género	Chilean-language term for gender-focused innovation in higher education (<i>Innovación en Educación Superior con enfoque de Género</i>)
CLP	Chilean peso
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUREs	Course-based Undergraduate Research Experiences
PhD	Doctor of Philosophy
MATIK	Estonian-language term used for integrated mathematics, science, technology, engineering and arts education (<i>matemaatika, teadus, tehnoloogia, inseneeria ja kunst(id)</i>)
EUR	Euro
ECTS	European Credit Transfer and Accumulation System
AI4Health.Cro	European Digital Innovation Hub for artificial intelligence and health in Croatia
EURES	European Employment Services
EIT	European Institute of Innovation and Technology
CERN	European Organization for Nuclear Research
EU	European Union
GRIT@Gov	GRaduate Industry Traineeships in government
GRIT	GRaduate Industry Traineeships
CTeSP	Higher Professional Technical Programme, Curso Técnico Superior Profesional
CIFRE	French-language term for Industrial Agreements for Training through Research (<i>Conventions industrielles de formation par la recherche</i>)
ICT	Information and communication technology
IT	Information technology
IMST	German-language term for Supporting School Excellence through Innovation (<i>Innovationen Machen Schulen Top</i>)
JSPS	Japan Society for the Promotion of Science
JRC	Joint Research Centre of the European Commission
KTH	KTH Royal Institute of Technology (<i>Kungliga Tekniska Högskolan</i>)
MSc	Master of Science
MINT	German-language term for <i>mathematics, computer science, natural sciences and technology</i> (<i>Mathematik, Informatik, Naturwissenschaften und Technik</i>)
MLG	Mutual Learning Group
NIMS	National Institute for Materials Science, Japan

Abbreviation/acronym	Full description
NSF	National Science Foundation, United States
LUMA	Finnish-language term for natural sciences and mathematics (<i>luonnontieteet ja matematiikka</i>)
LUMATE	Finnish-language term for natural sciences, mathematics and technology or technical fields (<i>luonnontieteet, matematiikka, tekniikka ja teknologia</i>)
NTNU	Norwegian University of Science and Technology
OECD	Organisation for Economic Co-operation and Development
GBP	Pound sterling
PISA	Programme for International Student Assessment
STEM	Science, technology, engineering and mathematics
STEAM	Science, technology, engineering, arts and mathematics
SGD	Singapore dollar
SWOT	Strengths, weaknesses, opportunities and threats
DTK	Hungarian-language term for Student Counseling Center (<i>diáktanácsadó központ</i>)
OPE	Student Trajectory Observatory at the University of Aveiro
TU	Technical University
UNESCO	United Nations Educational, Scientific and Cultural Organization
UK	United Kingdom
USD	United States dollar
UCL	University College London
UNSW	University of New South Wales
VET	Vocational education and training

Executive summary

Advanced skills in science, technology, engineering and mathematics (STEM) are essential to discovery, innovation and the responsible development and use of technology. In this report, advanced STEM skills are defined by the depth, combination and application of skills needed to address complex problems and not in terms of specific fields of study, qualifications or occupations. Advanced STEM skills comprise disciplinary, interdisciplinary, transversal and professional competence. Scientific and artificial intelligence (AI) literacy provide foundations for advanced STEM skills by enabling people to assess evidence and AI outputs, understand their limitations and use them responsibly.

Advanced STEM skills develop cumulatively through education, research and professional experience and require continuous skills renewal. Opportunities to develop, demonstrate, use and renew advanced STEM skills are unequally distributed. Learners differ in access to relevant school subjects, high-quality teaching, guidance, financial support, specialist programmes, research experience, professional placements and networks. These differences affect who enters and completes STEM education, progresses to advanced levels and demonstrates advanced STEM skills in practice and renews advanced STEM skills across working life. Inequalities may continue in employment, where personal circumstances and employer practices influence whose skills are recognised, used and further developed. Policymakers seeking to broaden the STEM talent base in national economies therefore need to pay attention to structural barriers in education and employment.

STEM is a useful policy construct for connecting education, research, innovation and employment and supporting co-ordination, priority setting and monitoring across these policy portfolios. Its use should not, however, imply that STEM is a single homogeneous category with fixed boundaries. Fields grouped under STEM also differ in their disciplinary foundations, provision costs, capacity requirements, educational and professional routes, and patterns of demand. Policymaking needs to take this into account. Investment in STEM should also be considered within the broader public purposes of higher education, including education and research across the natural sciences, mathematics, engineering, the arts, humanities, social sciences and other fields. Sustaining advanced STEM skills does not require placing STEM in opposition to these disciplines. Significant reductions in their capacity can weaken the interpretive, behavioural, ethical, legal and creative knowledge needed to define and address major societal challenges. Challenges such as improving healthcare, for example, require scientific and technological advances to be connected with knowledge of human behaviour, institutions, culture, ethics and the conditions under which innovations are introduced and used.

Shortages of advanced STEM skills are difficult to detect and interpret. Qualifications and occupational classifications provide useful but incomplete evidence. Advanced STEM skills may be used outside formally classified STEM occupations, while not every STEM job requires advanced skills. Employment in a STEM role does not mean that work requires sufficient complexity, autonomy or professional judgement. Recruitment difficulties may indicate insufficient supply, but may also reflect demand for experienced specialists, narrow recruitment criteria, pay and working conditions, geographical constraints, weak onboarding or employers' limited ability to recognise and use available competence. Skills analysis and planning should therefore examine the causes of reported shortages rather than assume that more STEM graduates are needed.

Drawing on in-depth discussions in the Mutual Learning Group on Advanced STEM Skills Development in Higher Education, organised by the OECD Secretariat, the report presents a framework for diagnosing bottlenecks, defining policy priorities and developing effective strategies for advanced STEM skills. Chapter 1 maps five interconnected bottlenecks: entry into STEM higher education; persistence and completion; progression to advanced levels; career entry and effective skills use; and skills renewal across working life. The framework identifies where constraints become visible in the development, use and renewal of advanced STEM skills, while recognising that they may originate earlier, accumulate across transitions or continue from education into employment. It sets out common questions to help policymakers define the observed pattern, identify the advanced STEM skills, fields, levels, population groups and locations concerned, test possible explanations, select and sequence suitable policy instruments, allocate responsibilities and assess the capacities and resources required.

Chapter 2 presents four areas for policy action: enabling entry, persistence and completion in STEM education; enabling progression to advanced STEM expertise and skills renewal across working life; renewing STEM programmes; and improving career entry and the effective use and continued development of advanced STEM skills. The relevance of each priority depends on national, regional and institutional conditions. Each considers the rationale for public intervention, intended outcomes, implementation requirements and potential risks. Examples from Europe, Asia-Pacific, North America and beyond illustrate possible approaches, implementation conditions and unintended consequences of policy intervention.

Chapter 3 explains how governments and other stakeholders can use the bottleneck framework and policy priorities to diagnose constraints, identify and sequence strategic responses, allocate responsibilities and align policy ambitions with sustainable implementation capacity. Its eight areas for policy action are intended to inform the design, implementation and evaluation of national strategies for advanced STEM skills and support co-ordinated action across education, science, technology, innovation and employment policy portfolios.

The report concludes with eight areas for policy action to strengthen the development and effective use of advanced STEM skills. These areas highlight the role of higher education institutions in skills development and policy learning.

1

Developing and using advanced STEM skills: Five interconnected bottlenecks

This chapter defines advanced science, technology, engineering and mathematics (STEM) skills as disciplinary, interdisciplinary, transversal and professional competence applied to complex scientific and technological problems and responsible innovation, including ethical, societal and environmental implications. It explains why these skills matter, but also why reported shortages require careful interpretation. It examines the benefits and limitations of using STEM as a policy construct and introduces a framework for diagnosing and assessing five interconnected bottlenecks in advanced STEM skills: entry into higher education; persistence and completion in higher education; progression to advanced levels; career entry and effective skills use; and skills renewal across working life.

Key issues

Advanced STEM skills comprise four dimensions of competence: disciplinary, interdisciplinary, transversal and professional. These skills develop cumulatively across education and working life, and often their development is not linear as learners may move between education, research and employment, interrupt and resume learning, or move across fields and occupations.

The purpose of using advanced STEM skills as a concept is not to introduce a new statistical category or draw a fixed boundary around particular qualifications or occupations. It is to provide an analytical lens for examining how these skills are developed, deepened, connected, used and renewed; where barriers arise; and which policy interventions may address them effectively.

Shortages of advanced STEM skills are difficult to measure and interpret. Recruitment difficulties may reflect gaps, but also demand for experienced specialists, narrow recruitment criteria, working conditions or employers' limited capacity to fully recognise and use available skills.

Five interconnected bottlenecks can constrain the development and effective use of advanced STEM skills. These concern entry into STEM higher education; persistence and completion; progression to advanced levels; career entry and effective skills use; and skills renewal across working life. The framework helps identify where a bottleneck becomes visible and examine the individual, institutional, organisational and system conditions that may produce it. Constraints can accumulate across education and working life or be transferred from one bottleneck to another.

Opportunities to develop, demonstrate, use and renew advanced STEM skills are unequally distributed. Gender, socio-economic background, geography, disability and migration background can interact and reinforce one another, shaping access to preparation, education, professional experience during study and access to suitable jobs. Addressing these barriers while maintaining high standards can broaden the talent base in STEM education, research and innovation.

Why advanced STEM skills matter

Discovery often begins without a clear view of whether or how the resulting knowledge will find practical application. Curiosity-driven inquiry enables people to investigate the unknown and question existing explanations, producing knowledge whose importance may become clear only over time. Many advances that transform health, technology, the economy and daily life originate in attempts to understand phenomena rather than meet an immediate practical need.

Science and technology expand what societies are capable of doing, but they do not determine which possibilities should be pursued, how competing objectives should be reconciled or how benefits, risks and responsibilities should be distributed (Feynman, 1955^[1]). These decisions require ethical and societal judgement as well as scientific and technical knowledge. They also require openness about uncertainty, critical scrutiny of assumptions and evidence, and a willingness to identify and correct error. These requirements become particularly important as discoveries give rise to technologies that move from research into complex economic and societal settings, where their consequences depend on how they are designed, interpreted, introduced and governed.

Consider a hospital introducing an artificial intelligence (AI) system to support clinical decisions. Computer scientists and statisticians may develop the model, but clinical specialists must determine whether its outputs are medically meaningful. Engineers and data experts must connect it with existing systems and assess whether the underlying information is reliable. Legal and ethical expertise is needed to address

privacy, accountability and bias. Health professionals must understand when to use the system, when to question its outputs and how to explain decisions to patients. Psychologists can contribute knowledge of how people interpret and respond to automated advice. Designers, artists and specialists in visual communication can help make the human-machine interface comprehensible and examine how the presentation of information may influence behaviour. Managers must co-ordinate these contributions and determine how the technology fits into clinical practice.

None of these individuals need to possess every relevant form of expertise. General AI literacy may enable participants to understand that an AI system has limitations and should not be followed uncritically. Advanced STEM skills are required to determine whether the data and model are appropriate for the clinical purpose, validate performance across relevant populations, integrate the system with clinical and organisational processes, interpret uncertainty, redesign the system or its use where necessary, and assume professional responsibility for consequential decisions. The institutional and system conditions matter for the development of advanced STEM skills, and this is where policymaking can make a difference by investing in education and research, widening access to substantive learning and research opportunities, and sustaining the people, infrastructure and institutional capacity on which scientific and technological progress depends.

What are advanced STEM skills?

Advanced STEM skills concern the depth, combination and application of competence needed to address complex scientific and technological problems. They are not limited to specific fields of study, qualifications or occupations. Based on analysis of existing literature and evidence from practice, this report defines advanced STEM skills as a combination of four dimensions of competence:

- **Disciplinary competence** provides depth in a scientific, technological, engineering or mathematical field, including command of its concepts, methods and standards of evidence.
- **Interdisciplinary competence** enables people to integrate concepts, methods, evidence and perspectives from different fields around a shared problem.
- **Transversal competence** enables people to communicate, collaborate, think critically, solve problems and continue.
- **Professional competence** enables people to apply knowledge and methods responsibly in occupational, organisational and regulatory settings. It includes the capacity to contribute to innovation, entrepreneurship and knowledge transfer, and to work at the interfaces between science, policy, regulation and public administration, including by translating scientific and technical evidence for different purposes.

The relative importance of the four dimensions of competence varies across roles and situations. Education can develop all four dimensions through disciplinary and interdisciplinary study, authentic problems, research, practical experience and engagement with professional settings. Their further development and integration continue through research and work, as people apply their competence under specific organisational, institutional and regulatory conditions and assume greater autonomy and responsibility. Professional competence may, for example, involve developing and scaling an innovation, transferring knowledge between research and application, creating or managing an enterprise, advising policymakers, designing or implementing regulation, or applying scientific evidence in public administration.

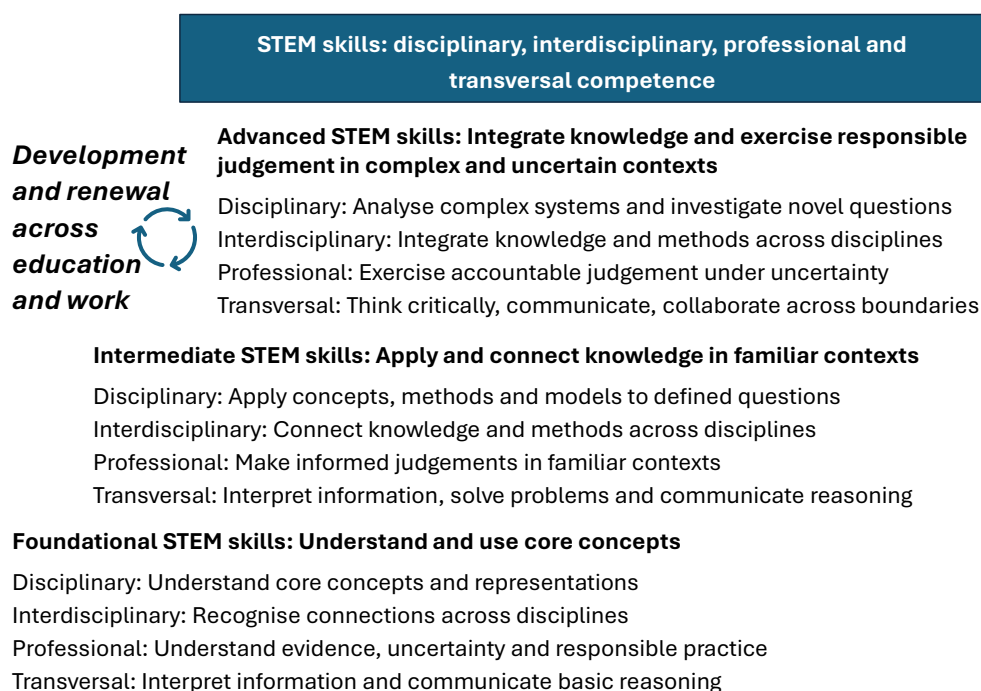
Opportunities to undertake substantive work, exercise judgement and assume increasing responsibility enable people to develop more advanced levels of this competence. Its continued development therefore depends not only on the competence individuals possess, but also on whether organisations create roles and working conditions in which it can be used and extended. It requires people to recognise uncertainty and the limits of their competence, consider the ethical and societal consequences of their decisions,

understand the institutional and regulatory contexts in which decisions are made, and remain accountable for how they interpret, communicate and use evidence.

Different levels of STEM skills can be distinguished according to the depth of knowledge involved, the complexity and familiarity of the context in which knowledge is applied, and the degree of integration, autonomy and judgement required (Figure 1.1.).

Advanced STEM skills differ from foundational and intermediate STEM skills in the depth, integration and judgement with which the competence dimensions are applied to a task. They enable people to work with greater disciplinary depth and to integrate knowledge across fields, address unfamiliar or complex problems, evaluate uncertainty and limitations, exercise autonomy and professional judgement, and develop, adapt or govern new knowledge and technologies. The staircase illustrates how these dimensions may be developed, combined and renewed across education, research and work.

Figure 1.1. Development and renewal of advanced STEM skills



Source: Goos, Carreira and Namukasa (2023^[2]), "Mathematics and interdisciplinary STEM education: Recent developments and future directions", <https://doi.org/10.1007/s11858-023-01533-z>; Archer et al. (2015^[3]), "Science capital: A conceptual, methodological, and empirical argument for extending Bourdieusian notions of capital beyond the arts", <https://doi.org/10.1002/tea.21227>; Global STEM Alliance (2025^[4]), STEM Education Framework Research Base, <https://www.nyas.org/wp-content/uploads/2025/05/STEM-Education-Framework-Research-Base.pdf>; and OECD (2026^[5]), PISA 2025 Assessment and Analytical Framework, <https://doi.org/10.1787/86c36975-en>.

Scientific literacy and AI literacy provide essential foundations for advanced STEM skills. They enable individuals and organisations to assess the basis, reliability and limitations of scientific claims, reported evidence, and importantly outputs generated by AI. Definitions for both literacies exist. Scientific literacy includes understanding how scientific knowledge and evidence are produced and evaluated (OECD, 2026^[5]), while AI literacy includes understanding, using and critically evaluating AI systems and considering their ethical and societal implications (OECD/European Commission, 2026^[6]; UNESCO, 2024^[7]; Long and Magerko, 2020^[8]). Basic scientific literacy is measured internationally among 15-year-old learners through the OECD Programme for International Student Assessment (PISA), while

frameworks and assessment instruments for AI literacy remain under development, including for the planned PISA 2029 assessment of media and AI literacy.

The purpose of using advanced STEM skills as a concept is not to introduce a new statistical category or draw a fixed boundary around particular qualifications or occupations. It is to provide an analytical lens for examining how disciplinary, interdisciplinary, transversal and professional competence is developed, deepened, connected, used and renewed; where barriers arise; and which policy interventions may address them effectively.

Disciplinary depth and integration across fields

Many contemporary challenges in STEM fields and beyond have technical, environmental, social and organisational aspects that cannot be addressed adequately through a single disciplinary perspective. Addressing them effectively (and efficiently) requires people to extend their disciplinary competence into adjacent fields or combine it with knowledge and methods from other domains. Interdisciplinary learning commonly involves integration around substantive problems, inquiry, design and collaboration (Portillo-Blanco et al., 2024^[9]; Rana, Aitken and Chimoriya, 2025^[10]).

Interdisciplinary competence can be described as a set of skills that allow an individual to apply disciplinary knowledge while integrating concepts, methods, evidence and perspectives from different fields around a shared problem, research question or design challenge. It requires more than exposure to several disciplines. Essential is to understand how the contributing fields define problems, produce and evaluate evidence, and assess possible solutions, as well as how their contributions can be combined. Interdisciplinary competence therefore depends on sufficient disciplinary depth to judge the quality and limitations of each contribution (Ashby and Exter, 2018^[11]; Portillo-Blanco et al., 2024^[9]).

Mathematics can support integration of knowledge, methods and evidence from different fields through modelling, abstraction, quantitative reasoning, and the analysis of relationships, variability and uncertainty. However, it may be treated only as a service tool within work framed by another discipline. Effective integration requires mathematics to contribute to problem formulation, model construction, analysis and interpretation rather than only to calculation (Goos, Carreira and Namukasa, 2023^[2]; Makonye and Moodley, 2023^[12]). This explains the central role of mathematics in advanced STEM skills.

There has been quite some development in the introduction of interdisciplinary programmes in STEM higher education. Table 1.1 distinguishes disciplinary, multidisciplinary, interdisciplinary and transdisciplinary provision as analytical categories and not part of a hierarchy. Programme titles do not typically provide information on the disciplinary depth developed, how knowledge and methods are integrated or which educational and professional routes a qualification provides access to. It is therefore needed to make explicit what programmes contain.

Table 1.1. Forms of disciplinary organisation and integration in advanced STEM programmes

Organisation	Main characteristic	Key features
Disciplinary	Learners study one STEM field in depth, using its distinctive concepts, methods, representations and standards of evidence.	Strong disciplinary identity and clearly sequenced learning objectives; supports depth, conceptual progression and specialised knowledge; limited explicit connection with other STEM fields.
Multidisciplinary	Several STEM fields address a common theme or problem, but each discipline retains separate learning objectives, teaching activities and assessment.	Shared topic or context, with contributions organised in parallel; separate disciplinary objectives, teaching and assessment; limited synthesis or integration across disciplines.
Interdisciplinary	Concepts, practices and ways of thinking from two or more STEM fields are deliberately connected in addressing a shared problem.	Reciprocal integration and shared problem-solving; identifiable disciplinary contributions; explicit conceptual and methodological connections across fields; joint application of approaches such as mathematical modelling, scientific inquiry, computational thinking and engineering design.

Organisation	Main characteristic	Key features
Transdisciplinary	Academic disciplines and non-academic, professional, community or experiential knowledge are combined around a complex real-world problem.	Organisation around a complex real-world problem; integration of academic disciplines with professional, community or experiential knowledge; disciplinary boundaries become less distinct as different forms of knowledge are mobilised around the problem.

Source: Based on Kelley and Knowles (2016^[13]), “A conceptual framework for integrated STEM education”, <https://doi.org/10.1186/s40594-016-0046-z>; Tytler, Anderson and Williams (2023^[14]), “Exploring a framework for integrated STEM: Challenges and benefits for promoting engagement in learning mathematics”, <https://doi.org/10.1007/s11858-023-01519-x>; and Goos, Carreira and Namukasa (2023^[2]), “Mathematics and interdisciplinary STEM education: Recent developments and future directions”, <https://doi.org/10.1007/s11858-023-01533-z>.

Advanced STEM skills as a strategic policy priority

Advanced STEM skills create economic and societal value through their effective development, renewal and application. For this, people need to be able to enter and complete high-quality STEM education, progress to advanced levels, gain access to substantive professional experience and suitable employment, and renew their skills as knowledge, technology and professional practice change. Employers need to be able to interpret relevant competence, recruit people with appropriate foundations, provide effective onboarding and organise work so that advanced STEM skills inform professional practice and organisational decisions. There are several bottlenecks that effective policymaking needs to address.

Demand for advanced STEM skills is increasing across countries with implications for education and employment. The 2024 European Employment Services (EURES) report on labour shortages and surpluses, for example, identified widespread shortages in engineering, software development and other information and communication technology occupations, as well as in construction and healthcare. Employer surveys, vacancy data and sectoral assessments can help policymakers identify where pressures are concentrated. However, these sources do not always distinguish clearly among insufficient supply of specific skills, broader labour shortages, mismatches between employer requirements and candidate profiles, and recruitment difficulties associated with pay, working conditions or location (EURES, 2024^[15]; European Commission, 2023^[16]; OECD, 2022^[17]).

In the United Kingdom, for example, the 2025 Quantum Skills Taskforce identified shortages in engineering and technical occupations needed to develop and diffuse quantum technologies. Many of these occupations are also in demand elsewhere in the economy, creating competition among quantum organisations and other sectors for people with relevant skills. The Taskforce therefore emphasised specialised education and training, stronger connections among education, research and industry, and the development of technical roles supporting the wider adoption of quantum technologies (UK Government, 2025^[18]).

In Japan, the adoption of AI has increased demand for workers able to develop, implement and use AI systems. A 2025 Linux Foundation survey found a positive net hiring effect from the introduction of AI among the organisations surveyed but also reported that more than 70% of employers lacked sufficient employees with AI-related skills. Japan’s response places considerable emphasis on skills renewal among the existing workforce, including opportunities for workers to develop digital and AI-related competence during their careers. This reflects the importance of responding to technological change through continuing education and workplace learning as well as through initial education (The Linux Foundation, 2025^[19]).

Korea has combined domestic skills development with measures intended to attract international researchers and postgraduate learners in strategic fields, including semiconductors, biotechnology, quantum technologies and AI. The government has expanded its long-running Brain Pool programme and introduced financial and immigration-related incentives intended to attract international researchers, specialists and postgraduate learners (Byeongseon, 2026^[20]).

Australia faces reported shortages across a range of specialised engineering fields, including aeronautical, biomedical, electrical, environmental, geotechnical, marine, mining, petroleum and water engineering.

Engineers Australia has called for a national engineering workforce strategy connecting government policy, higher education funding and changing industry needs (Engineers Australia, 2025^[21]).

The OECD Research and Innovation Careers Observatory provides a complementary evidence base for examining these questions across countries. Its comparative indicators cover the size and composition of the research and innovation workforce, talent renewal, employment across different parts of the labour market, career outcomes, working conditions and international mobility. This evidence can help policymakers distinguish constraints affecting the development, circulation, employment and retention of research and innovation personnel rather than interpreting reported pressures solely as shortages of graduates (OECD, 2026^[22]).

Europe's Education Strategic Plan: Skills for Competitiveness and Innovation

For the European Union, advanced STEM skills have gained particular importance. They are considered crucial to Europe's capacity to raise productivity, reduce innovation gaps and advance the green and digital transitions. Demographic change adds to this challenge by reducing the working-age population and increasing the importance of broadening participation, supporting skills renewal and making effective use of the competence already available.

The European Commission's 2025 STEM Education Strategic Plan: Skills for Competitiveness and Innovation, adopted as part of the Union of Skills, reflects the growing strategic importance attached to STEM education in Europe (European Commission, 2025^[23]). Its actions are organised around three objectives: establishing STEM as a strategic pillar of European education, skills and economic policy; strengthening and broadening the STEM talent base; and reducing barriers to participation, particularly for girls and women (Box 1.1).

Box 1.1. Europe: A STEM Education Strategic Plan: Skills for Competitiveness and Innovation

The European Commission adopted the Communication "A STEM Education Strategic Plan: Skills for Competitiveness and Innovation" in March 2025 as part of its Union of Skills strategy. The Plan responds to concerns about Europe's productivity and innovation performance, changing demand for skills in key technology sectors, a shrinking working-age population, declining performance in mathematics and science, persistent gender disparities and difficulties attracting and retaining STEM talent. It connects STEM education and training with competitiveness, the green and digital transitions, preparedness, technological leadership and strategic autonomy, and organises action around three objectives:

- **Lead:** establish STEM as a strategic pillar of EU education, skills and economic policy. Proposed actions includes encouraging national and regional STEM strategies, strengthening intelligence on emerging skills needs and graduate outcomes, and creating a European STEM Executive Panel to advise on strategic issues and improve cross-portfolio policy co-ordination.
- **Level up:** develop a stronger and more inclusive STEM talent base. The Plan seeks to improve the quality and relevance of STEM education, strengthen connections between education, research and employment, and support learning in fields important to Europe's future competitiveness. Proposed actions include developing an EU STEM competence framework, supporting joint programmes and specialist training in strategic sectors, and exploring a European degree for engineers.
- **Lift barriers:** widen participation and address obstacles affecting underrepresented groups.

The Plan proposes EU-level targets for 2030 to guide progress at EU level and to be supported by national or regional strategies.

Area	Participation target	Inclusion target
STEM in initial medium-level vocational education and training	At least 45% of learners	At least 25% female participation
STEM in tertiary education	At least 32% of students	At least 40% female participation
ICT doctoral education	At least 5% of students	At least one-third female participation

Source: European Commission (2025^[23]), *A STEM Education Strategic Plan: Skills for Competitiveness and Innovation*, COM(2025) 89 final, European Union, Brussels, eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025DC0089; European Commission (2025), *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions: The Union of Skills*, COM(2025) 90 final, European Union, Brussels, eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025DC0090.

The STEM Education Strategic Plan illustrates the value of treating advanced STEM skills as a strategic priority at European level. A common framework can raise visibility, establish shared objectives and support co-ordination across education, research, innovation and employment. Its aggregate targets can provide direction and a basis for monitoring progress across the European Union. Their interpretation and implementation nevertheless require more detailed diagnosis at national, regional and institutional levels. Similar aggregate outcomes may reflect different constraints across STEM fields, qualification levels, locations and population groups, while progress towards a participation target does not by itself show whether learners can persist, complete, progress to advanced levels or use and renew their advanced STEM skills. Member States therefore need to translate the Plan's shared objectives into priorities and responses suited to their education systems, labour markets, institutional capacity and identified constraints.

Recent evidence from the United States demonstrates the policy importance of treating STEM talent development as an interconnected system rather than as separate interventions in education, research, employment and immigration matters. Zegart and Johnston (2026^[24]) find that weaknesses in domestic preparation and progression increase reliance on international recruitment, while growing global competition and immigration constraints make attraction and retention less certain. International students earned 51% of US STEM master's degrees and 39% of STEM research doctorates, yet the proportion remaining after graduation fell below stated intentions. These mutually reinforcing pressures show why policy needs to address the full set of conditions through which people develop, apply and continue to renew advanced STEM skills, rather than concentrating on enrolment or graduate supply in isolation. The report also illustrates the value of combining evidence across education, research, employment and migration, since no single indicator or dataset can establish whether a country is developing and using advanced STEM skills effectively. The five interconnected bottlenecks examined below in the chapter provide a framework for assessing these relationships across the development, renewal and use of advanced STEM skills.

Why shortages in STEM skills are difficult to diagnose

Workforce shortages refer broadly to imbalances between the workers available and those sought for particular work. A labour shortage arises when too few people are available or willing to work under prevailing pay and working conditions, while a skills shortage arises when employers cannot obtain particular skills (Brunello and Wruuck, 2021^[25]; Polanco-Jimenez and Witte, 2025^[26]). Labour shortages can be assessed through indicators such as vacancy rates, recruitment times and wage trends.

Skills shortages are harder to assess because the skills available and required cannot usually be observed directly, qualifications and occupations provide only imperfect proxies, skill requirements change over time,

recruitment difficulties may have causes other than insufficient skills, and employment indicators do not show whether advanced STEM skills are used effectively (OECD, 2022^[17]).

Qualifications could be used as an indicator, but they are an imperfect proxy for skills for two reasons. On the one hand, credentials signal the skills developed through education, but they do not always accurately reflect individuals' actual capabilities in practice. Weak alignment between qualifications and skills, due to differences in learning quality, specialisation, and practical experience, makes it difficult for employers to assess what workers can do and, in turn, to measure real skills shortages (Spence, 1973^[27]; Arrow, 1973^[28]). On the other hand, the demand for skills is constantly evolving. As technologies and work practices change, the competencies required by employers also shift, particularly in advanced STEM fields (Acemoglu and Restrepo, 2019^[29]). This can create gaps between what is taught and what is needed in practice: graduates may hold relevant degrees but lack up-to-date or applied skills if education and training systems do not keep pace with technological change. Together, imperfect signalling and rapidly changing demand make it challenging to define, identify, and measure skills shortages with precision.

Advanced STEM skills are also used beyond occupations formally classified as STEM occupations, making their supply and use more difficult to assess. Examples illustrate this. The widespread adoption of digital technologies and AI has made skills in areas such as data analysis, modelling, systems integration and technology-informed decision making relevant across a growing range of occupations and sectors. Emerging fields such as quantum technologies provide another example. Their research, development and adoption involve scientists, engineers and technicians, but also managerial and other professional roles in sectors such as finance, healthcare and advanced manufacturing. Analysis confined to conventional STEM occupations may therefore overlook workers and skills (EPO/OECD, 2025^[30]).

Furthermore, employer-reported recruitment difficulties do not necessarily indicate a skills shortage. They may also reflect pay and working conditions, geographical constraints, narrow or unrealistic recruitment requirements, demand for experienced specialists, or limited employer investment in onboarding, training and continued development (Sostero and Fernández-Macías, 2021^[31]). Recruitment difficulties therefore need to be interpreted alongside evidence on job requirements, candidate profiles, wages, location, working conditions and employer practices.

Employment in a STEM occupation or a role requiring a STEM qualification does not necessarily mean that advanced STEM skills are used effectively. Workers may undertake tasks offering limited complexity, autonomy, problem solving, professional judgement or opportunities for continued development. Conversely, graduates employed outside their field of study or outside an occupation formally classified as STEM may make extensive use of scientific, quantitative, computational or engineering competence.

In sum, distinguishing among these forms of underutilisation affects how apparent shortages are interpreted (Box 1.2). Evidence on tasks and actual skills use is therefore needed to determine whether advanced STEM skills are being applied effectively across occupations and sectors (Xu, 2012^[32]; More and Rosenbloom, 2020^[33]; Yin and Wang, 2026^[34]).

Box 1.2. Conceptualising graduate skills underutilisation

Skills underutilisation refers broadly to a situation in which workers possess skills that are not fully required, applied or rewarded in their work. It can be examined across four related but distinct dimensions:

- **Qualification mismatch** compares a worker's educational attainment with the qualification level required for the job. Overeducation occurs when attainment exceeds the level normally required.

- **Field-of-study mismatch** concerns whether the content of a worker's education corresponds to the field in which they work. Employment outside the field of study does not necessarily mean that advanced STEM skills are unused, since scientific, quantitative, computational and other transferable competence may be applied elsewhere.
- **Skills mismatch** compares a worker's competence with the skills required by the job. Skills underutilisation occurs when existing competence is used insufficiently, for example because work provides limited task complexity, autonomy, problem-solving or professional judgement.
- **Employment underutilisation** concerns the amount or conditions of employment and may include involuntary part-time work, insufficient hours, low earnings or limited career progression. It does not necessarily imply that the worker's skills are poorly matched to the tasks performed.

These dimensions may overlap, but they identify different groups of workers and should not be used interchangeably. Qualification correspondence, field relevance and occupational classification provide indirect evidence, while information on tasks, autonomy and actual skills use gives a more direct indication of whether advanced STEM skills are being applied.

STEM is not a monolithic category

STEM as a policy concept gained influence partly in response to concerns about workforce needs, productivity, innovation and competitiveness (Box 1.3). In many countries, it provides a practical framework for bringing together science, technology, engineering and mathematics and for connecting education policy with research, employment and industrial development. It can raise the visibility of scientific and technical education, support co-ordination across policy areas and provide a basis for differentiated investment where programmes require costly infrastructure, specialist staff or additional teaching capacity.

However, the apparent coherence of STEM as a priority selection of disciplines can conceal substantial differences. Definitions may differ among education, employment and statistical systems. Education authorities may identify STEM through fields of study, while labour-market authorities use occupations, competencies or job tasks. For example, the EU STEM Education Strategic Plan (see Box 1.1) uses a programme- and field-based classification covering the ISCED-F (2013) fields of natural sciences, mathematics and statistics; information and communication technologies; and engineering, manufacturing and construction, as well as related interdisciplinary programmes. Importantly, common classifications of STEM do not include agriculture, forestry, fisheries and veterinary; and health and welfare – also fields which develop advanced STEM skills. Regardless of which fields are grouped under the acronym, they tend to have very different provision costs, capacity constraints, progression routes and patterns of demand.

Treating STEM as a strategic priority should not place it in opposition to the humanities, arts and social sciences as responsible innovation and sustainable growth requires knowledge and skills that draws on both STEM and non-STEM fields. Scientific and technological developments take shape within social, cultural, economic, legal and political contexts, and decisions about their purposes and use require knowledge and judgement from across these fields. Presenting investment in STEM as requiring reduced attention to other disciplines may narrow the knowledge available to define problems, assess consequences and guide the responsible application of science and technology.

Box 1.3. STEM as a policy construct

The term science, technology, engineering and mathematics (STEM) can refer to programmes of study, qualifications, occupations, competencies or research activity. These approaches overlap, but they capture different populations and serve different analytical purposes. Countries differ in how they define and use STEM, reflecting differences in industry, education systems, labour markets, and regulations. As a result, there is no single global definition.

The boundaries of STEM have also broadened in some policy and educational contexts through the use of STEAM or STE(A)M, which makes explicit the contribution of the arts, humanities and social sciences to creativity, design, communication and the responsible application of technology.

- **STEM education programmes** are usually identified through classifications of fields of study. OECD comparisons generally include natural sciences, mathematics and statistics; information and communication technologies; and engineering, manufacturing and construction. National classifications may differ, however, and the treatment of interdisciplinary programmes and fields related to agriculture, health, sustainability or the green transition is not uniform.
- **STEM qualifications** certify completion of assessed programmes identified as STEM. They provide evidence of formal attainment, but qualifications with similar titles or at the same level may differ in content, specialisation, practical experience and assessment. They therefore do not provide a complete measure of the competence available or used.
- **STEM occupations** are identified through occupational classifications, sometimes supplemented by information on the competencies or tasks associated with particular jobs. National and international classifications do not always draw the same boundaries. Moreover, advanced STEM skills are used in occupations not formally classified as STEM, while people within the same occupational category may undertake tasks requiring different forms and levels of expertise.
- **STEM research** is generally classified through disciplinary fields, publications, patents or research activities. Emerging and interdisciplinary areas may not fit established categories, and classifications of research do not necessarily correspond to classifications of education or employment.

Despite the definitional variability, STEM remains a useful policy construct. It can focus attention on the capabilities required for scientific and technological development, help actors from education, research, employment and industry identify shared concerns, and support co-ordination across policy areas. However, its use should not imply that STEM is a single homogeneous category with fixed boundaries.

Broadening the talent base

Meeting changing needs for advanced STEM skills requires education systems to draw on learners with a wide range of backgrounds who have aspirations, preparation and potential. This involves more than widening access and expanding participation. A broader talent base also expands the perspectives and questions represented in research and innovation. Large-scale empirical studies indicate that researchers' characteristics are associated with the topics they study and that under-represented groups produce comparatively high rates of scientific novelty. However, their novel contributions may be less readily taken up, recognised and rewarded when they originate outside established scientific networks and perspectives (Hofstra et al., 2020^[35]; Kozłowski et al., 2022^[36]).

A group is under-represented when its participation falls below an appropriate benchmark. Which benchmark is appropriate depends on the policy question. Participation may be compared with the general population, learners at the preceding educational level, those who meet relevant entry requirements or those eligible for a specific opportunity. For example, the share of women entering doctoral education may be compared with their share among eligible master's graduates in the same field. Both representation and transition rates should be considered, since similar participation shares may conceal differences in application, selection, continuation or progression.

Broadening the talent base must be accompanied by conditions that enable different perspectives to influence innovation and receive appropriate recognition. It also means ensuring that access to the educational opportunities needed to develop and demonstrate advanced STEM skills does not depend unnecessarily on learners' starting points or circumstances. The OECD concept of inclusive excellence in science and the research workforce provides a useful basis for this approach. Inclusive excellence means maintaining high standards while embedding equity in the conditions through which people gain access to education, training, opportunities and recognition, so that differences unrelated to their ability to contribute do not determine their prospects of success (OECD, 2025^[37]). Applied to advanced STEM education, this means preserving the depth and quality of educational pathways while identifying and addressing avoidable constraints on who can develop advanced STEM skills.

Broadening participation and perspectives in advanced STEM

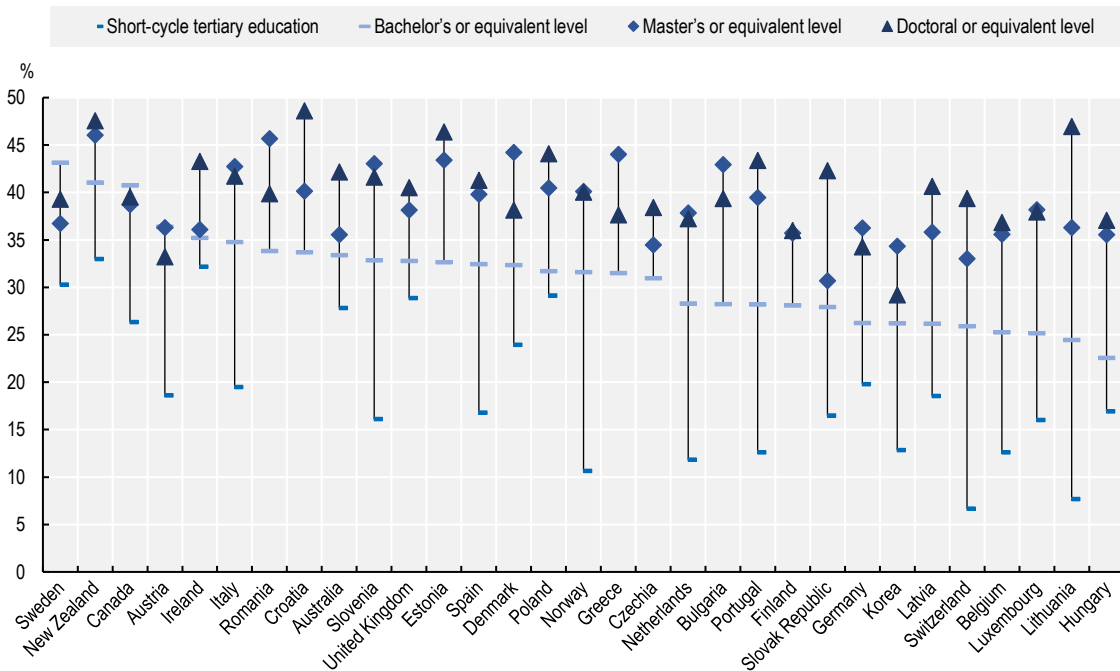
Gender is the most visible and comparatively well-documented dimension of under-representation (Eurostat, 2026^[38]; European Commission, 2025^[39]). Figure 1.2 shows that across countries women are under-represented in core STEM. Women account for 31% of bachelor's enrolment on average, and no country reaches gender parity at any level of study. National differences are nevertheless substantial, ranging from more than 40% of bachelor's enrolment in Sweden, New Zealand and Canada to around one-quarter in Hungary, Lithuania, Luxembourg, Belgium and Switzerland. Under-representation is particularly pronounced in short-cycle tertiary education, where women account for only 19% of enrolment on average.

Representation increases at higher levels of study, rising from 31% at bachelor's level to 39% at master's level and 40% at doctoral level. However, this should not be interpreted as evidence of equitable progression. The figure compares enrolment at different educational levels in a single year rather than following individuals over time. It therefore cannot show whether women progress at the same rate as men or identify where differences emerge in application, admission, continuation or completion. Moreover, changes in the composition of enrolment across STEM fields may increase the female share at higher levels even where representation remains stable or declines within individual fields. Low representation of women in short-cycle tertiary STEM programmes may reflect differences in the disciplinary composition, occupational orientation and role of these programmes across national systems. However, the available data do not allow the causes of these patterns to be identified, and further analysis is required.

Women make up roughly one-third of STEM graduates at bachelor's and master's levels, but only around one-fifth of doctoral graduates in ICT and less than one-third in engineering. Women's representation among doctoral graduates has declined since 2018 in several narrower STEM fields, including physics and mathematics, where they were already underrepresented. Women also hold less than one-third of senior academic positions and around one-quarter of institutional leadership roles (European Commission, 2025^[39]). Participation at one level therefore does not ensure equitable progression to the next. OECD evidence further indicates that gender differences continue across research and innovation careers and may concern participation in different fields and sectors, international mobility, employment conditions and longer-term career outcomes. Examining representation at successive education levels is therefore insufficient: analysis also needs to follow who enters research and innovation work, the roles and conditions they experience, and whether they can progress and remain in these careers (OECD, 2026^[22]).

Figure 1.2. Women remain below parity in core STEM enrolment across countries and levels of study

Female students as a percentage of all students enrolled in core STEM, by level of education, 2024



Note: Values show female students as a percentage of all students enrolled in core STEM at the level indicated. Core STEM comprises natural sciences, mathematics and statistics (ISCED-F 05), information and communication technologies (ISCED-F 06) and engineering, manufacturing and construction (ISCED-F 07). Countries are ranked in descending order of the female share of bachelor's enrolment. Data on short-cycle tertiary education are not available for all countries, and short-cycle provision is limited or absent in several systems.

Source: OECD (2026^[40]), *Number of enrolled students, graduates and new entrants by field of education*, (database), OECD Data Explorer, <https://data-explorer.oecd.org/s/5ky>.

StatLink  <https://stat.link/5f0kiz>

Examining equitable progression requires also information on who can access the learning, mentoring, research and professional opportunities that support educational and career transitions. The STEM Atlas shows how mapping initiatives can complement official statistics by making the distribution of such opportunities more visible. Developed by STEM Women and Global STEM Women, the approach has been used first in Spain, then also in, Brazil, Canada, Colombia Italy and Portugal, mapping more than 700 initiatives. While official data track enrolment, graduation and employment, they provide less information on outreach, mentoring, extra-curricular programmes, professional networks and similar activities. The Atlas collects information on the groups and educational or career stages reached, geographical coverage, activities and funding, and compares it with demographic and education data (Global STEM Women, 2026^[41]; Díaz, 2026^[42]). It can show where provision is concentrated and where particular places, groups or transitions receive limited support.

The wider issue is that access to mentoring, paid research experience, internships, professional networks, leadership and entrepreneurship opportunities is uneven. Mapping can make some of these differences visible where enrolment and graduation data cannot. However, the presence of an initiative does not

establish its accessibility, quality or effects. An initiative may not reach learners facing the greatest constraints or provide substantive opportunities to develop advanced STEM skills.

Assessing whether policy responses reflect this range of connected constraints requires looking across the full education and professional route. The UNESCO STEM and Gender Advancement (SAGA) project illustrates how a systemic approach can be used to identify gaps in the conditions supporting participation and progression (UNESCO, 2018^[43]). It was launched in 2015 and maps policies and indicators across seven objectives covering social norms and stereotypes, primary and secondary education, higher education, career progression, research content and practice, policymaking, and entrepreneurship and innovation. Across the pilot exercises, career progression was addressed by the largest number of identified policies and instruments, followed by participation and retention in higher education. These are areas in which governments, higher education institutions, research organisations and employers have relatively direct instruments, including recruitment and promotion procedures, scholarships, mentoring, parental-leave provisions and childcare support.

Social norms and stereotypes were widely identified in the pilot exercises as a major constraint but were addressed by relatively few instruments. This reflects the difficulty of assigning responsibility for influences that operate across families, schools, institutions, workplaces and wider society and whose effects may become visible only over time. Research content and practice and science- and technology-based entrepreneurship and innovation also received comparatively limited attention, particularly in countries where these had only recently emerged as policy priorities.

The pilot exercises show why broadening the talent base requires attention not only to the number of measures adopted, but also to their distribution across the stages and settings in which inequalities arise. A concentration of measures in one area does not establish that it is the most important source of inequality or that it is being addressed adequately, while limited policy activity may indicate that a constraint is difficult to assign to a single actor or address through a discrete instrument. Assessing the contribution of interventions such as SAGA, or UNESCO's Campus Africa initiative, which brings together higher education institutions, governments and other partners to strengthen research and innovation, doctoral study and mobility, and higher technical education across Africa (UNESCO, 2026^[44]), requires looking beyond the existence and scale of provision to examine which learners and institutions it reaches, the quality of their participation, and whether it produces sustained educational, research and employment outcomes

Unequal access and participation extend beyond gender

Although gender is the most visible and best-documented dimension of under-representation in STEM, similar questions arise for other groups whose opportunities to participate and progress may be shaped by their circumstances and the barriers they encounter.

Socio-economic background can affect whether learners encounter STEM early, gain the preparation and information needed to pursue it, and can afford the direct and indirect costs of advanced study (Betancur, Votruba-Drzal and Schunn, 2018^[45]; Morgan et al., 2016^[46]). Geography can limit access to relevant programmes, research infrastructure and employment opportunities. Learners with disabilities may encounter inaccessible teaching, assessment, laboratories or infrastructure (Borrego et al., 2025^[47]). Learners with migration backgrounds may face barriers related to language, access to information and guidance, and the recognition of qualifications and previous learning (European Commission, 2024^[48]).

The effects of these factors depend on how individual circumstances interact with educational, institutional and labour market conditions. Barriers can become more significant when advanced study requires relocation, extensive laboratory attendance or unpaid professional experience; when teaching and infrastructure are inaccessible; or when language requirements, unfamiliar qualifications and limited networks restrict access to educational and professional opportunities.

These circumstances can intersect and reinforce one another (Crenshaw, 1989^[49]; Bauer et al., 2021^[50]). Financial constraints may combine with disability-related costs, caring responsibilities or distance from suitable provision. Migration status may interact with qualification recognition, language barriers and limited access to networks. Policy should therefore examine how learners' circumstances interact with educational, institutional and system conditions to shape access to preparation, substantive learning opportunities and progression.

Evidence is often thinnest where several dimensions intersect. Data availability and public discourse differ substantially across countries, and some countries do not collect data on ethnicity or migration background, limiting both national analysis and cross-country comparison (European Commission, 2025^[51]). Small sample sizes can restrict reliable analysis, while data categories and legal frameworks differ. Administrative records may show participation without revealing the conditions that shaped it. Analysis should therefore be explicit about these limitations and, where comparable quantitative data are unavailable, use qualitative and initiative-level evidence cautiously to identify constraints that aggregate indicators may conceal (European Commission, 2025^[51]; Bauer et al., 2021^[50]).

In Europe, joined efforts across countries and stakeholders have resulted in a growing evidence and policy infrastructure. “She Figures”, the European Commission’s flagship statistical publication on gender equality in research and innovation, provides comparable, disaggregated indicators that follow women’s and men’s trajectories from doctoral education through research employment to senior academic, leadership and decision-making positions. It also covers working conditions and research and innovation outputs, enabling countries and institutions to identify disparities and monitor change over time. Institutional action is supported through so-called Gender Equality Plans. Under Horizon Europe, having such a plan is an eligibility condition for public bodies, higher education institutions and research organisations when applying for public funding (European Commission, 2025^[52]; Karataş, Löther and Weber, 2025^[53]).

No equivalent EU-wide statistical or funding frameworks exist for socio-economic background, disability, migration background or other relevant circumstances. Evidence and policy responses in these areas are more difficult to compare. Most countries address these groups primarily through general higher education access and student support measures.

These differences in opportunity and policy coverage cannot be located at a single stage. They may arise in preparation and entry into STEM education; access to substantive learning opportunities; persistence and completion; progression to advanced levels; transition into suitable employment; early-career development; or skills renewal. They can also accumulate across the transitions among these points. Understanding where the talent base is unnecessarily narrowed therefore requires a framework that distinguishes the principal locations and mechanisms of constraint while recognising their interdependence.

Five interconnected bottlenecks in the development and effective use of advanced STEM skills

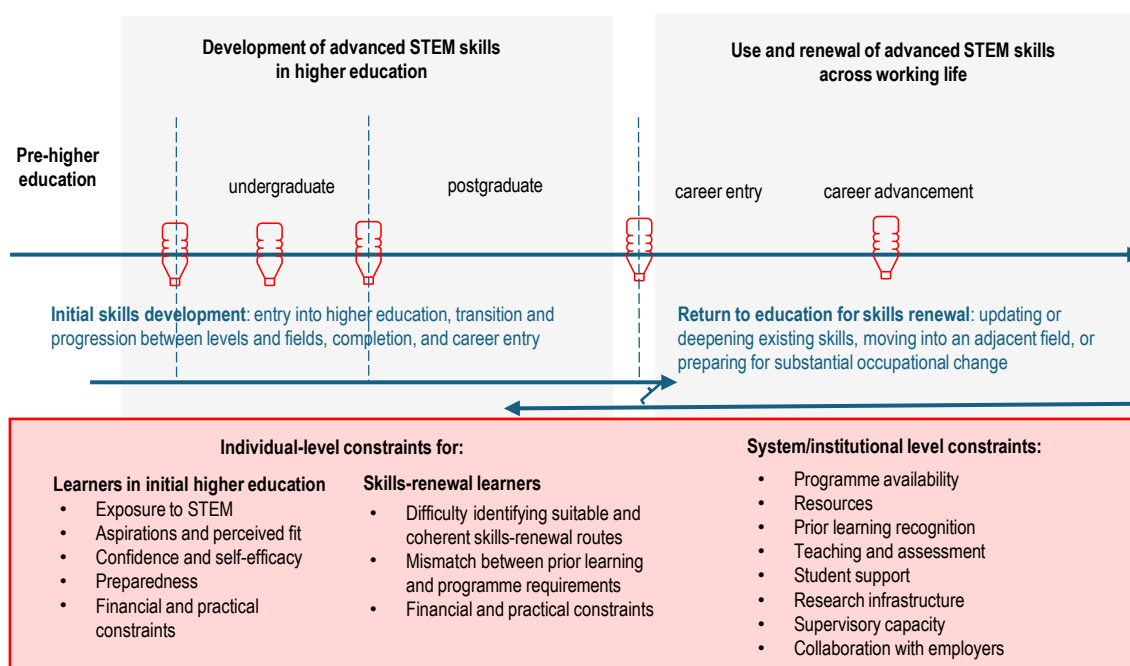
Advanced STEM skills are developed, used and renewed through routes connecting education and employment. These routes may begin with foundations acquired during school education and continue through vocational education and training, higher education, advanced study, employment and continuing education.

Figure 1.3 distinguishes the initial development of advanced STEM skills from their use and renewal across working life. Initial development typically includes entry into higher education, transition and progression between levels and fields, completion and career entry. Skills renewal may involve updating or deepening existing advanced STEM skills, moving into an adjacent field or preparing for substantial occupational change. It may include a return to education at undergraduate or postgraduate level, depending on the

learner's previous competence and intended destination. These routes are not necessarily linear. Learners may move between education sectors, change fields, interrupt and resume study, enter employment before completing a qualification, or return to education as the requirements of their work or career direction change. The same course may therefore contribute to initial skills development for a learner completing a first higher education qualification and to skills renewal for a learner returning with previous education or professional experience.

Constraints can become visible at different points along these routes and manifest in bottlenecks in entry into STEM higher education, persistence and completion, progression to advanced levels, career entry and effective skills use, and skills renewal across working life (Figure 1.3). Diagnosing these bottlenecks requires evidence from across education and employment. Education evidence can reveal patterns in preparation, entry, persistence, completion, progression and attainment, while employment evidence can show where individuals work and where demand may be changing. Evidence from employers and workers can provide information on recruitment, changing tasks, competence requirements, working conditions and actual skills use. No single perspective establishes whether the relevant advanced STEM skills are being developed and used in sufficient depth, in the relevant fields and locations, or for the purposes concerned.

Figure 1.3. Bottlenecks in the development and effective use of advanced STEM skills



Source: Authors based on literature review, and discussions in the Mutual Learning Group on Advanced STEM skills development in higher education.

Many policies examined in this report are relevant to STEM education more broadly as the development of advanced STEM skills is cumulative: access to strong foundations, high-quality teaching, progression, research and professional experience is necessary before advanced competence can be developed and demonstrated. The focus on advanced STEM skills guides policy analysis to assess whether a system allows learners and workers to develop, use and renew these skills.

Where the causes of a bottleneck may lie

The point at which a bottleneck becomes visible does not necessarily show what causes it. To analyse the latter, it is helpful to consider that constraints may arise in four analytically distinct but connected locations: through individuals' access to educational and professional opportunities, within higher education institutions, within employers, and in wider system arrangements (Table 1.2).

Table 1.2. Constraints on the development and effective use of advanced STEM skills

Constraint level	Main constraint	Underlying mechanisms
Individual	Access to the opportunities needed to develop and demonstrate advanced STEM skills is unequally distributed	Learners and workers have unequal access to preparation, research and professional experience, information, networks and suitable employment. Financial, geographical, personal and opportunity costs restrict participation, progression and return to education, particularly where routes assume continuous full-time participation.
Higher education institution	Gaps in institutional capacity and inflexible provision constrain learning, progression and the visibility of competence	Institutions may lack the pedagogical, organisational and resource capacity to design and deliver coherent programmes, provide connected student support, enable research and professional experience, accommodate interruption and return, serve adult learners, monitor structural barriers and communicate the disciplinary, interdisciplinary, transversal and professional competence developed.
Employer	Limited capacity to recognise, absorb and develop advanced STEM skills restricts their effective use at work	Employers may have difficulty specifying and validating the competence required, apply narrow recruitment criteria, expect organisation-specific knowledge before entry, provide insufficient onboarding, assign routine or narrowly bounded work, and offer limited feedback, development, specialist advancement or sustainable working conditions.
System	Fragmented responsibilities and partial interventions leave connected barriers unresolved	Responsibility is distributed across education, research, innovation, employment, industrial, regional and social policy. Aggregate STEM indicators can obscure field-, level- and region-specific constraints. Short-term funding, weak co-ordination and monitoring of activities rather than connected outcomes limit sustained action. Policies may address individual outcomes without changing the systemic conditions that produce them.

Note: The four locations are analytical categories, not fixed levels of responsibility. System arrangements shape the responsibilities, resources and incentives of higher education institutions and employers. Institutional and employer practices, together with financial, geographical and personal circumstances, determine which opportunities individuals can access. A constraint may therefore become visible in one location while originating partly or wholly in another, and outcomes generally arise through interactions among them.

The role and capacity of higher education

Higher education has a distinctive role in the development of advanced STEM skills because it develops and assesses advanced disciplinary and methodological learning, connects education with research, provides access to specialist infrastructure and recognised qualifications, and supports progression to advanced study and skills renewal. Its contribution depends also on the wider system arrangements within which institutions operate.

The capacity of higher education institutions includes:

- **pedagogical capacity**, including curriculum design, teaching, assessment, feedback, supervision and academic support
- **organisational capacity**, including programme leadership, co-ordination, guidance, connected learner services, partnerships, recognition, and the collection and use of evidence for improvement
- **resource capacity**, including qualified academic, technical and support staff, specialist infrastructure and research environments, staff time, data and analytical capacity, and sustainable funding

These forms of capacity are interdependent. The adequacy of institutional capacity depends not only on the number of available programme places, but also on student-to-staff ratios, class and laboratory group sizes, teaching intensity, supervisory workloads, staff expertise, and access to technical and learner-support staff. Additional places will not increase the supply of advanced STEM skills if staffing, infrastructure and organisation are insufficient to provide high-quality teaching, practical learning, supervision, feedback and support. These requirements may be particularly demanding in fields relying on specialist teaching, laboratories, research environments and disciplinary communities, and thus more challenging for smaller systems.

Specialist infrastructure requires continuing investment. Laboratories, equipment, computing and data environments, and physical facilities need to be operated, maintained, calibrated, repaired, replaced and updated as methods, technologies and safety requirements change. Practical teaching creates recurring costs for laboratory materials, software, data access, technical preparation, safety and waste management. Initial investment therefore creates sustainable capacity only when institutions can also finance operation, maintenance and renewal.

Staff time and institutional incentives are an important part of capacity. Curriculum renewal, pedagogical improvement, collaborative teaching, feedback, programme leadership and partnership-based provision require sustained work alongside research, supervision and other responsibilities. Where workload allocation and career evaluation give limited recognition to teaching, curriculum development and educational leadership, these functions may depend on temporary funding or a small number of committed staff. Institutions therefore need to allocate sufficient time and recognise substantive contributions to teaching and programme improvement in appraisal and career progression.

Institutions also need the data and analytical capacity to identify where learners encounter barriers, how programme experiences and outcomes differ, and whether changes improve learning and progression. This requires more than collecting participation, completion or satisfaction data. Programme leaders and institutional decision makers need evidence that can connect learner outcomes with curriculum, teaching, assessment, workload, support and access to practical and research opportunities. Data should support learners and programme improvement rather than operate primarily as a means of classifying individual risk.

Higher education capacity affects all five bottlenecks. Increasing entry without sufficient staff, infrastructure and learner support may restrict access to practical learning and weaken teaching and feedback. Expanding advanced study without adequate supervision, research infrastructure and funding may reduce quality or delay completion. Skills-renewal provision may remain inaccessible if programmes, recognition arrangements and learner services are designed mainly for recent school-leavers studying full-time. Research and professional experience may produce uneven benefits if access, learning objectives, responsibilities, supervision and quality assurance are unclear.

The importance of policy dialogue and how it was applied in preparing this report

Constraints differ across fields, qualification levels, population groups, institutions and locations, and the same observed outcome may arise from different mechanisms. These differences make policy dialogue important. Quantitative indicators can identify patterns, and research can provide evidence on the mechanisms that may produce them. Interpreting their policy relevance, however, also requires knowledge of how education systems, higher education institutions, employers and public authorities operate in different contexts. Policymakers, researchers and higher education practitioners bring complementary perspectives on where constraints arise, which actors can influence them, what implementation requires and why similar measures may produce different results. Dialogue across countries can help identify common bottlenecks while distinguishing their context-specific causes. It can also support comparison of policy priorities and areas for policy action without assuming that the same response should be transferred directly between systems.

This principle was applied in preparing this report. The report was developed through an iterative process that combined literature review, comparative data analysis, desk-based policy analysis and structured dialogue through the Mutual Learning Group on Advanced STEM Skills in Higher Education, organised by the OECD Secretariat (see Annex A for more information). The group brought together policymakers, researchers, higher education practitioners and other experts with experience from Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Denmark, Estonia, Finland, Germany, Ireland, Japan, Korea, Poland, Portugal, Spain and Trinidad and Tobago, as well as participants from the European Commission's Joint Research Centre, UNESCO and the European Organization for Nuclear Research (CERN).

The Mutual Learning Group provided a lens through which the literature, data and policy analysis could be interpreted for their policy relevance, implementation requirements and applicability across contexts. This helped bring the different sources of evidence together and organise the findings into a framework intended to inform policymakers.

Discussions in the group drew attention to institutional and system conditions that may be less visible in published research and evaluations, including fragmented responsibilities, limited staff time, unstable funding, insufficient infrastructure, difficulties in co-ordinating actors and the practical limits of transferring an approach between settings. The dialogue also helped test the relationships among bottlenecks, policy priorities and areas for policy action, including whether similar bottlenecks appeared across countries, which mechanisms produced them and how action at one point could create or relieve pressure elsewhere.

The resulting framework distinguishes five points at which constraints on the development and effective use of advanced STEM skills become visible.

Bottleneck 1: Entry into STEM programmes in higher education

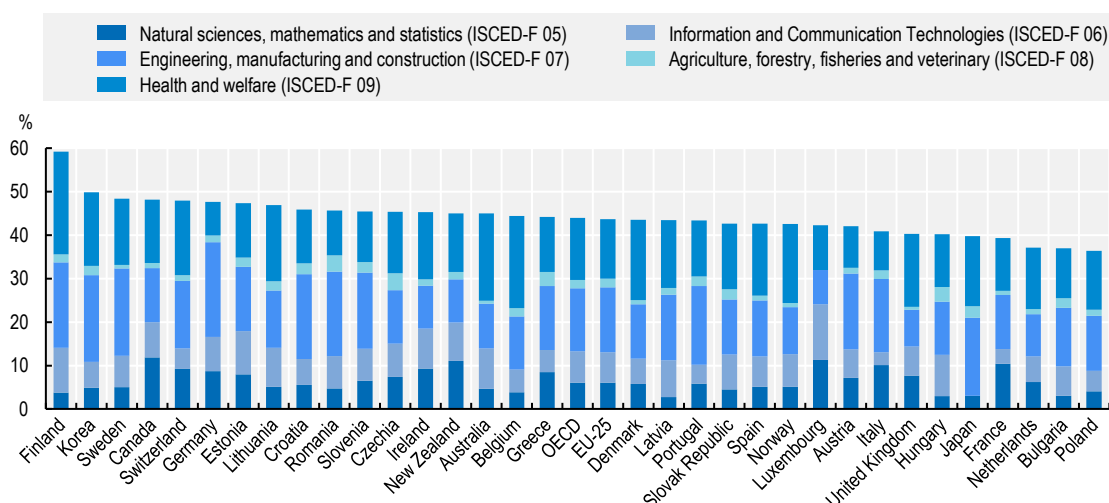
Entry into STEM higher education varies substantially across countries and fields. Core STEM accounts for 28% of new tertiary education entrants on average across both EU and OECD Member States, but national shares range from 21% to 38%. Across countries, growth in entry has been limited overall. OECD and EU data indicate that the average number of new STEM entrants changed only modestly between 2015 and 2023, although trends differed substantially across countries and fields. Growth was stronger in information and communication technologies than in engineering or the natural sciences.

Figure 1.4 shows the share of new tertiary entrants in the three core STEM fields and in two additional science-intensive fields: agriculture, forestry, fisheries and veterinary; and health and welfare. Countries are ranked by the combined share of entrants across all five fields. National figures for new entrants into core STEM fields range from 38% in Germany, followed by Finland at 34%, Estonia at 33%, and Sweden and Luxembourg at 32% each, to 21% in Belgium and Poland and 22% in the Netherlands. This 17-percentage-point range among systems facing broadly similar technological and demographic pressures directs attention towards conditions in particular national contexts rather than a uniform European pattern.

The combined share by which countries are ranked in Figure 1.4 should not be interpreted as a measure of core STEM entry. Finland records the highest combined share at 59%, but health and welfare alone accounts for 24% of its new entrants, the highest value in the comparison, while its core STEM share of 34% remains below Germany's. Germany ranks sixth on the combined measure at 48%, while recording both the highest core STEM share, at 38%, and the lowest share entering health and welfare, at 8%. Belgium illustrates the same point more sharply: its combined share of 44% is close to the OECD average, but its core STEM share of 21% is the lowest in the comparison because health and welfare accounts for 21% of new entrants. Aggregating fields with different patterns of entry, provision costs and capacity constraints can therefore produce a measure that moves independently of core STEM entry.

Figure 1.4. The share of new entrants to STEM fields differs significantly across countries

New entrants to core STEM and science-intensive fields as a share of all new tertiary entrants, 2024



Note: Countries are ranked in descending order of the combined share of all five fields. Data refer to 2023 for Bulgaria, Czechia, Denmark, Finland, France, Greece, Hungary, Italy, Japan, Lithuania, Portugal, Sweden, the OECD average, and the European Union (25 countries). Data on information and communication technologies are not available for Japan, and its combined share is correspondingly understated. Core STEM fields comprise natural sciences, mathematics and statistics (ISCED-F 05), information and communication technologies (ISCED-F 06) and engineering, manufacturing and construction (ISCED-F 07). Science-intensive fields comprise Agriculture, forestry, fisheries and veterinary (ISCED-F 08) and health and welfare (ISCED-F 09).

Source: OECD (2026^[54]), *Distribution of enrolled students, new entrants and graduates by field of education*, (database), OECD Data Explorer, <https://data-explorer.oecd.org/s/550>.

StatLink  <https://stat.link/6nz7qu>

Composition also varies within core STEM. Entry into natural sciences, mathematics and statistics ranges from 3% in Latvia to 11% in Luxembourg and 10% in France and Italy, while entry into information and communication technologies ranges from 3% in Italy to 13% in Luxembourg. Engineering, manufacturing and construction, the largest core STEM field in most systems, varies less proportionately but more in percentage-point terms, from 8% in Luxembourg and the United Kingdom to 22% in Germany. Information and communication technologies account for a comparatively small share of entry in most countries, with a median of 7%, compared with 13% for engineering. Italy, where core STEM entry of 30% exceeds the EU average but entry into information and communication technologies is the lowest in the comparison, shows that a relatively high aggregate share does not imply balanced entry across fields.

Entry data reflects both learner demand and institutional supply. Learner demand concerns whether prospective learners are interested in applying to STEM programmes and have the necessary preparation, while institutional supply concerns whether sufficient, accessible and high-quality programme places are available. These point to different sets of constraints and policy responses.

Earlier subject choices and unequal preparation can restrict academic eligibility

School education shapes learners' interest in STEM and develops foundational competence. The structure of secondary education also affects access to higher education. Some systems require early specialisation, while others maintain a broader curriculum for longer. Early specialisation may limit later options, especially for learners who develop an interest in STEM later or have had limited access to relevant subjects (OECD, 2025^[55]).

Advanced mathematics and science subjects frequently operate as formal prerequisites for entry into higher education STEM programmes. Learners and their families may not understand that discontinuing advanced mathematics or science subjects in secondary education can exclude entry to certain higher education fields. Access to these subjects, the quality of their teaching, the timing of specialisation and the flexibility of secondary-higher education pathways can therefore open or close later opportunities. The effects may be particularly strong in systems that use early tracking, have rigid subject combinations or provide limited opportunities to supplement previous learning. Some schools may also be unable to offer the relevant subjects because of teacher shortages, inadequate facilities or cohorts that are too small.

Evidence from England (United Kingdom) indicates that a reform encouraging greater participation in mathematics during the final two years of secondary education increased entry to and completion of STEM undergraduate degrees. However, gender and socio-economic differences in STEM participation remained unchanged. The findings suggest that widening access to prerequisite subjects can increase progression into STEM but may be insufficient on its own to overcome the wider barriers affecting participation among under-represented groups (Morando, 2024^[56]).

Curriculum reforms can also have unintended effects. Following the reform of general upper-secondary education implemented in France from 2019, many students discontinued mathematics between the first and final years, with discontinuation more prevalent among female students. Mathematics provision was subsequently strengthened for students who did not take the mathematics specialisation. While these developments do not by themselves establish the reform's causal effects on entry to higher education, they highlight the importance of assessing how subject choices shape preparation and eligibility for subsequent programmes across population groups, and the need to monitor participation before and after reform (Dauphin, 2024^[57]; Ministry of National Education and Youth, 2023^[58]). Chapter 3 discusses the methodological challenges involved in distinguishing the effects of an intervention from wider changes, examining differences in implementation and outcomes across groups, and using the resulting evidence to inform policymaking.

Formal prerequisites may be academically justified where later learning depends on cumulative disciplinary foundations. However, there is a risk that requirements unnecessarily exclude learners who develop an interest in STEM after making earlier subject choices, enter through vocational education and training, move between education systems or return as adults. Bridge provision, meaning additional learning designed to address identified gaps, can provide another route into STEM programmes without removing substantive academic requirements. It may include supplementary mathematics courses, foundation years or preparatory courses before entry (Bokhove et al., 2019^[59]).

Teachers' professional backgrounds, beliefs and instructional practices are also associated with students' attainment, motivation and persistence in mathematics and science. These outcomes can, in turn, shape students' plans to pursue STEM-related studies and careers (Ekmekci and Serrano, 2022^[60]). In the natural sciences, practical activities can strengthen conceptual understanding and practical skills, but their effectiveness depends on how they are designed and taught (Oliveira and Bonito, 2023^[61]).

Mathematics experiences shape whether learners consider STEM attainable and attractive

Learners' interest in mathematics, confidence in their mathematical abilities and anxiety about the subject can shape their engagement and decisions about STEM education and careers. Mathematics self-efficacy refers to confidence in one's capacity to perform particular mathematical tasks successfully. Mathematics anxiety refers to feelings of tension, apprehension or fear associated with engaging in or anticipating mathematical learning, assessment and problem-solving. Mathematics interest is understood as enjoyment of, curiosity about and positive engagement with the subject (Bokhove et al., 2019^[59]).

Longitudinal evidence suggests that mathematics interest is a particularly consistent predictor of later STEM choices, while the relationships between self-efficacy, anxiety and STEM participation overlap with

prior achievement and other dimensions of learners' mathematical identities (Cribbs, Huang and Piatek-Jimenez, 2021^[62]; Ferdinand, Malanchini and Rimfeld, 2024^[63]). This does not make self-efficacy or anxiety irrelevant as potential constraints. Confidence may strengthen expectations of success and willingness to undertake challenging mathematics, while anxiety may encourage avoidance, reduce perceived control and make mathematically intensive programmes appear more difficult or personally costly. Longitudinal studies find that mathematics anxiety and self-efficacy are associated with subsequent STEM choices, but the available evidence does not establish that either factor independently causes later choices. Their influence may operate through or alongside interest, attainment and the learning environments in which these develop (Cuder et al., 2024^[64]; Ferdinand, Malanchini and Rimfeld, 2024^[63]). Anxiety is associated with less positive attitudes, avoidance and, in some contexts, weaker performance. These factors can reinforce one another over time: anxiety may encourage avoidance and reduce opportunities to develop proficiency, while weaker achievement and unsuccessful experiences may contribute to greater anxiety (Lau, Ansari and Sokolowski, 2024^[65]).

It is important to understand that interest, self-efficacy and anxiety are not fixed personal characteristics. They develop through learning experiences and may be influenced by curriculum, teaching practices, achievement, feedback and peer comparison, as well as socio-economic resources expectations about belonging, and stereotypes. Research on mathematics self-efficacy identifies reciprocal relationships with learning behaviour and achievement and highlights the role of environmental influences, including instructional practices and teacher feedback. Hence, learners with similar levels of performance may develop different levels of interest, confidence and anxiety and may view the same STEM route differently (Zakariya, 2022^[66]; Street, Malmberg and Schukajlow, 2024^[67]).

Aspirations lead to entry only when learners perceive that they can succeed and belong

Learners' decisions about STEM depend also on the futures they hope to pursue and whether they see a place for themselves in this by pursuing a certain study programme or career. Learners are more likely to choose STEM when they can envision a desirable future in the field and believe they can succeed and belong within it. These judgements are shaped by prior achievement, subject access, social recognition, role models, family and peer expectations, institutional environments and the perceived social meaning of different STEM fields (Archer et al., 2012^[68]; Archer et al., 2015^[3]).

Aspirations and perceived fit influence one another over time. Aspirations refer to the education or career futures learners aim to pursue, while perceived fit refers to whether they see a STEM field as attainable, valuable and compatible with their interests, identity and sense of belonging. Previous academic and social experiences shape how learners understand their abilities, interests, values and identities in relation to STEM. These perceptions affect whether they pursue relevant subjects and apply to STEM programmes. Later experiences may strengthen an aspiration, redirect it towards another field or route, or weaken it. Furthermore, learners may enjoy doing science without seeing themselves, or being recognised by others, as someone who could become a scientist (Archer et al., 2010^[69]; Carlone and Johnson, 2007^[70]).

Unequal access to preparation, encouragement, information, networks and recognition matter for aspirations and perceived fit. Gender, race or ethnicity, socio-economic background, family, school experience and role models can influence whether advanced STEM skills are considered achievable. Interest may therefore be insufficient where dominant images of STEM remain narrow or exclusionary (Archer, DeWitt and Osborne, 2015^[71]; Archer et al., 2016^[72]). Also, learners may decide not to apply for a programme because they doubt their ability to meet its perceived academic demands. Studies found that in physics academically qualified learners may opt out because they see the field as exceptionally difficult, masculine or suited only to a narrow group (DeWitt, Archer and Moote, 2018^[73]; Archer et al., 2016^[74]).

Information and guidance can widen options learners consider, but cannot remove barriers

OECD analysis of the 2022 PISA finds that 39% of 15-year-olds across OECD countries were uncertain about their future occupation and that occupational expectations remained concentrated in a narrow range of traditional professions, with substantial gender differences in aspirations towards engineering and information technology. Although 76% had explored careers online, only 55% had spoken with a career adviser, 45% had visited a workplace or participated in job shadowing, and 35% had completed an internship. These findings suggest that many learners lack sustained guidance and direct exposure to workplaces and people in work that could help them understand the diversity of STEM fields, the educational choices they require and whether these routes are attainable (OECD, 2025^[75]).

Information and guidance influence study choices by shaping awareness of available options, understanding of programme requirements, expectations about careers and confidence in navigating applications. Their contribution depends on whether they are timely, accessible, comprehensible and connected with opportunities that learners can realistically pursue (Rinn and Kettler, 2020^[76]). Furthermore, information and guidance expand the perceived choice set rather than persuade a learner to select a particular programme (Lent, Brown and Hackett, 1994^[77]). This is particularly relevant at initial entry because prospective learners often possess uneven knowledge of STEM fields. Medicine, engineering and computing may be familiar, while materials science, geoscience, data science, environmental engineering and biotechnology may be less known.

Effective guidance is not a one-off intervention as learners require information that helps them consider:

- **academic preparation:** whether previous subjects, qualifications and skills correspond to programme requirements, and whether gaps can be addressed
- **interests:** whether the content and activities of a particular field correspond to what they enjoy and want to explore
- **values:** whether a field offers opportunities for social contribution, creativity, collaboration, financial security or environmental improvement
- **belonging:** whether people with different identities and backgrounds participate and are recognised in the programme and related occupations
- **progression:** which routes are available after completion and what additional conditions apply.
- **employment prospects:** the range and quality of possible outcomes, without reducing the decision to salaries or aggregate demand

Effective guidance requires long-term efforts. However, access to information and guidance is unequal. School resources, career stereotypes, socio-economic background, family knowledge of higher education and peer choices influence what learners know and whether they can act on it. Learners may follow familiar routes or consider only programmes that seem suitable and attainable for “people like me”, even when they have similar interests and aspirations to others (DeWitt and Archer, 2015^[78]; Tompsett and Knoester, 2023^[79]; Andersen and Hjortskov, 2019^[80]; Rubineau et al., 2023^[81]; Archer et al., 2016^[74]; Du and Wong, 2019^[82]).

Role models can make STEM routes more visible, challenge stereotypes and provide practical information about study and careers. Their influence depends on whether learners see their success as relevant and attainable. However, role models alone are unlikely to make a difference, particularly when programmes remain unavailable, unaffordable or difficult to enter (Gladstone and Cimpian, 2021^[83]; De Gioannis, Pasin and Squazzoni, 2023^[84]).

Financial and practical costs can make a preferred STEM route unfeasible

STEM programmes are study-intensive and can therefore impose additional costs for learners. Family resources, borrowing capacity, access to paid employment and the timing of financial support affect whether a preferred choice is feasible in practice (Liu and Kringos, 2025^[85]).

Financial and geographical constraints tend to reinforce one another. Specialised STEM programmes and research infrastructure may be concentrated in a limited number of locations, while laboratory work, projects and placements may require substantial in-person participation. Where long-distance commuting is impracticable and affordable student housing is limited, learners may be unable to access programmes for which they are otherwise qualified.

Financial support can enhance STEM participation in two ways. It may make STEM study more attractive by reducing its costs and financial risks or help learners who already prefer STEM to act on that preference, and it can reduce the need to work during study, delay entry, choose a less suitable institution or forgo higher education (Zhao, Perez-Felkner and Hu, 2024^[86]; Romero, Cobian and Martín, 2025^[87]).

There are different forms of financial support and they address different barriers (Box 1.4). Need-based grants can make study affordable and reduce reliance on paid work. Merit-based scholarships can lower costs and recognise achievement, but demanding renewal conditions may discourage entry or continuation. Tuition waivers do not cover living costs, transport, childcare, equipment or lost earnings. Maintenance support can give learners more time for classes, laboratory work, projects and placements. The 2026 Erasmus+ policy experimentation call illustrates a more integrated approach: it is testing scholarships for academically strong students, particularly those from disadvantaged backgrounds, that cover the full costs of participation in selected strategic fields and combine study support with mobility and traineeships, internships, mentorships or industry placements (European Commission, 2026^[88]).

Box 1.4. Financial support instruments for STEM participation

Financial support can facilitate entry, persistence and completion by reducing financial pressure and reliance on paid work. Policymakers should identify which barrier an instrument addresses, for which learners and at what stage.

Need-based grants provide non-repayable support based on household resources or assessed financial need. They can make study feasible, reduce reliance on paid employment and help learners manage financial shocks. This is particularly relevant in STEM programmes with substantial scheduled teaching, laboratory work, projects and placements that limit opportunities to work alongside study.

Merit-based scholarships allocate non-repayable support according to attainment, performance, demonstrated potential, or other indicators of achievement. They reduce the cost of study and recognise achievement. However, strict renewal conditions may make demanding STEM programmes appear financially risky and encourage learners to avoid difficult courses or leave after a temporary decline in performance.

Tuition and fee waivers remove all or part of tuition or programme-specific charges and may be universal or targeted. They directly reduce the listed price of study but do not cover accommodation, food, transport, equipment, childcare or forgone earnings.

Living costs and maintenance grants contribute to housing, food, transport, childcare, equipment and other living costs. They can reduce financial pressure and free time for study, laboratories, projects and placements. They are particularly important where specialised provision requires relocation and affordable housing is limited.

Institutional capacity can limit both the number and quality of available places

Constraints in the capacity of higher education institutions can be particularly important at advanced levels and in fields requiring intensive teaching, supervision and research infrastructure as they may limit admission directly or lead institutions to restrict recruitment where additional enrolment would exceed the capacity supported by available staff, infrastructure and funding or weaken the quality of provision (OECD, 2025^[89]).

Expansion can produce unintended effects if enrolment grows faster than institutions' staffing, infrastructure and learner-support capacity. Time-limited or targeted funding may create unsustainable programmes, relabel existing provision or redistribute rather than expand capacity, while geographic concentration and employer funding may restrict access or narrow curricula. Capacity should therefore be assessed by relating the number of available and filled places to the staffing, infrastructure, supervision and learner support required for a high-quality learning experience. Indicators such as student-to-staff ratios, laboratory and equipment availability, class and group sizes, supervisory workloads and access to learner support can help determine whether existing or planned enrolment is adequately supported. Expansion is appropriate where demand is sustained, existing capacity is insufficient and additional investment can support high-quality provision.

Capacity constraints may be geographically concentrated where specialist facilities and staff are available in only a small number of institutions. Regional strategies may build capacity around existing research and economic strengths, while concentration in a small number of institutions may create the critical mass required for expensive or highly specialised fields. The appropriate balance depends on the field, the geographical distribution of learners and employment, and the extent to which mobility or shared provision is feasible.

Collaborative arrangements may allow institutions to share facilities, curricula, staff expertise and research environments. Deep, long-term and structured co-operation, such as the example of the European Universities alliances, can enable institutions to pool expertise, knowledge and resources and combine complementary strengths that may not be available within a single institution. Such arrangements can widen the educational and research opportunities available to learners, including in STEM and other strategic fields, but require aligned programme structures, compatible access and recognition arrangements, and sustainable organisational capacity across participating institutions (see example of European Universities alliances in Policy Priority 3.1).

Implications for diagnosing an entry bottleneck

Diagnosing an entry bottleneck requires evidence from learners, schools and higher education institutions, while responsibility for addressing identified constraints is distributed among schools, higher education institutions and public authorities, with employers contributing where constraints concern occupational information used in guidance and outreach.

Different aspects are relevant.

Diagnosis should follow learners through the stages leading to enrolment. Evidence on access to relevant subjects, attainment, eligibility, applications, offers, acceptance and enrolment can help identify where participation declines. Information from learners, schools and higher education institutions can then clarify whether the observed pattern reflects preparation, interest, confidence, programme awareness, perceived fit, application and admission arrangements, costs or institutional capacity. Analysis should examine the timing of constraints and whether they originate earlier than the point at which they become visible, and which groups are concerned. Curriculum and admission reforms should be monitored before and after implementation to assess their intended and unintended effects on subject participation, eligibility and entry.

Interest, confidence, anxiety, aspirations and perceived fit should not be treated as fixed characteristics of individual learners. They develop through prior learning, achievement, feedback, social recognition, stereotypes and educational environments. Learners may value a STEM field but doubt that they can meet its academic demands, belong within it or pursue the forms of work and social contribution they value. Where these factors constrain entry, responses may need to improve learning experiences, provide constructive feedback, widen representations of STEM study and work, and develop inclusive environments in which a wider range of learners can participate successfully.

Information and guidance should be assessed in relation to when it is provided, who can access it and whether learners can act on it. It should help learners understand programme content and requirements, possible routes into and beyond a programme, and the range and quality of associated employment opportunities. Information, guidance and role models can widen the options learners consider, but cannot compensate for routes that are inaccessible, unaffordable or unavailable.

Formal qualifications and prerequisites provide only partial evidence of preparation. Learners holding the same qualification may differ in the content and depth of their prior learning, the teaching they experienced and their opportunities to apply knowledge. Where preparation constrains entry, responses may need to widen access to relevant subjects and high-quality teaching, clarify how subject choices affect later eligibility and provide bridge provision and academic support for learners with identified gaps. Substantive prerequisites should be maintained where they are necessary for later learning, but learners need equitable opportunities to meet them.

Financial and practical barriers should be assessed beyond tuition costs. Diagnosis should consider participation and opportunity costs, including living costs, materials, transport, relocation, housing, childcare, lost earnings and the time demands associated with laboratory work, projects and placements. It should also examine whether geographical concentration and requirements for in-person participation restrict access. Financial support should address the specific barrier, learners and decision point concerned. Its coverage, amount, timing, accessibility and conditions should enable participation without making demanding STEM study appear financially risky.

The capacity of higher education institutions should be assessed by relating demand and the number of available and filled places to the staff, infrastructure, supervision, practical learning opportunities and learner support required for high-quality provision. Where capacity is insufficient, responses may include stable investment, shared provision or regional concentration, depending on the field, the critical mass required and the feasibility of learner mobility. Proposed expansion should be assessed for quality, sustainability, geographical accessibility and whether it creates additional capacity rather than relabelling or redistributing existing provision.

Bottleneck 2: Persistence and completion in STEM programmes

Persistence and completion are shaped by learners' preparation and circumstances, and by the conditions they encounter within programmes, including curriculum sequencing, teaching, assessment, feedback, belonging, learner support and institutional capacity. A bottleneck in persistence and completion arises when learners who have the interest and potential to meet programme requirements cannot continue or complete because of avoidable constraints.

STEM programmes often combine cumulative learning, sequenced prerequisites and substantial project and laboratory work. Research by Seymour and Hunter (2019^[90]) shows that losses during the early undergraduate years can affect also students who entered STEM with strong academic preparation. Their work challenges interpretations that attribute departure primarily to insufficient ability or commitment and directs attention towards the learning experiences students encounter. In particular, fixed beliefs about intelligence can support a selective view of teaching in which introductory courses are expected to identify the relatively few students presumed to have the capacity to succeed, rather than enable a wider range of

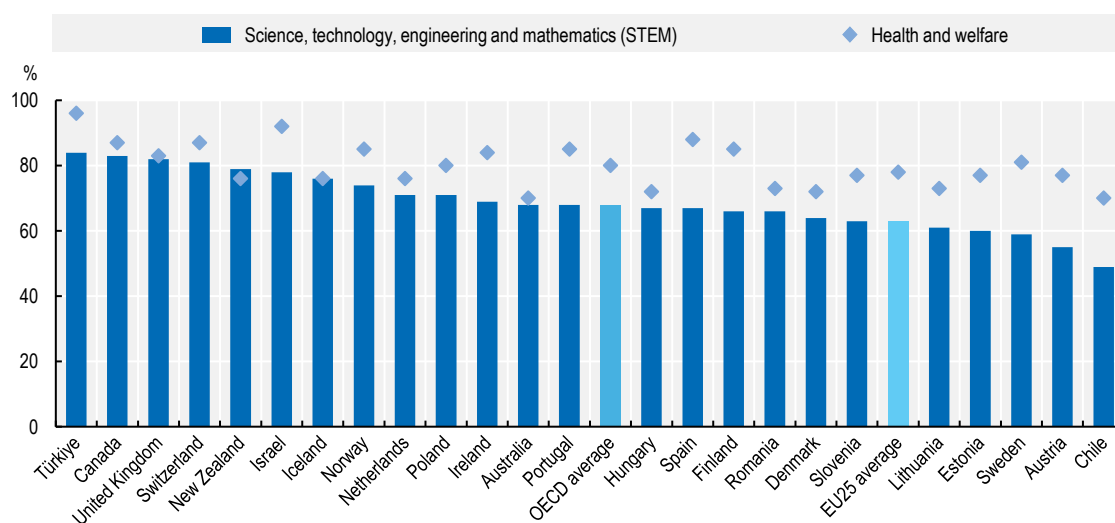
learners to continue. Fixed beliefs can lead to resistance to reconsidering teaching and assessment. Diagnosis should therefore examine not only which learners leave or change route, but also how programmes define ability, organise early learning and assess whether teaching enables students to make progress.

It is important to distinguish constructive changes of route from displacement by avoidable barriers. Transfer may lead to a programme better aligned with a learner's interests, preparation or objectives, while temporary interruption may allow a learner to manage their personal circumstances and later return. Measures of persistence and completion should therefore distinguish withdrawal from transfer, interruption, continued enrolment and completion in another programme or field.

Figure 1.5 shows the proportion of full-time new entrants to bachelor's programmes who had completed a qualification three years after the theoretical end of their programme, in STEM and in health and welfare. Because the indicator covers full-time entrants only, it does not provide a complete picture in systems where part-time study is common. The figure presents an aggregate completion rate; complementary indicators are needed to distinguish continued enrolment, completion after changing field and departure from higher education among learners who had not completed by the observation point.

Figure 1.5. STEM bachelor's completion rates vary across countries

Completion rates of new entrants into bachelor's programmes by the end of the theoretical duration of their programme plus three years (2023)



Note: The students included in this survey are those who were new entrants to a tertiary level of education and who were full-time students at the time they entered the programme. The year of reference (2023) corresponds to a period three years after the theoretical end of the programmes these students entered, 2021 to one year after the theoretical end and 2020 to the theoretical end. The year of reference for Colombia is 2022.

Source: OECD (2025^[91]), *Education at a Glance 2025: OECD Indicators*, Table B5.3, <https://doi.org/10.1787/1c0d9c79-en>.

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Across OECD countries, 68% of full-time new entrants to STEM bachelor's programmes had completed three years after the theoretical programme duration, compared with 63% across the EU25. Outcomes vary widely, from 84% in the Republic of Türkiye and 83% in Canada to 49% in Chile. Among the EU Member States shown, the range is narrower but remains substantial, from 71% in Poland and the Netherlands to 60% in Estonia, 59% in Sweden and 55% in Austria. Completion in STEM is lower than in

health and welfare in almost every country shown. The average difference is 12 percentage points across OECD countries and 15 percentage points across the EU25, where 63% of STEM entrants completed compared with 78% in health and welfare. The gap reaches 22 percentage points in Sweden and Austria and 21 in Spain. It is small in the United Kingdom, absent in Iceland and reversed in New Zealand, where STEM completion is 3 percentage points higher than for health and welfare.

The differences between STEM and health and welfare may reflect variation in the characteristics and prior preparation of entrants, admission arrangements and the conditions learners encounter within programmes. Relevant programme conditions include curriculum structure and sequencing, prerequisite requirements, practical learning and institutional capacity.

The aggregate STEM rate also conceals differences among its constituent fields. Separate field-level data for the countries for which they are available indicate that completion in information and communication technologies is often below the national average across fields. Natural sciences, mathematics and statistics also record comparatively low completion, while outcomes in engineering, manufacturing and construction are more mixed. The difference between completion in any field and completion in the field of initial entry also indicates that some learners complete after changing field.

Explaining these patterns requires programme-level and learner-level evidence on where difficulties arise, which learners are affected and how they experience the conditions within their programmes. The following sections examine these conditions, beginning with programme culture and its influence on whether learners participate, seek help and recover from setbacks.

Programme cultures and collaborative learning influence participation, belonging and persistence

Sense of belonging can shape both whether learners choose a field and whether they persist once enrolled. It is a concept for whether a learner feels accepted, respected, supported and valued. It can influence willingness to participate, seek assistance and continue after setbacks (Strayhorn, 2018^[92]). Learners are more likely to persist when they develop meaningful relationships with peers, educators and the professional communities associated with their field.

Belonging is shaped by everyday experiences, including classroom climate, interactions with peers and educators, teaching practices, opportunities to participate, and recognition of learners' identities and contributions. It is an individual experience and an outcome of pedagogical and institutional arrangements (Duncan, Holt and Keenan, 2023^[93]; Valdez and Kelp, 2023^[94]). Highly competitive or exclusionary environments may discourage questions, collaborative study and contact with academic staff. Programme and institutional cultures can weaken belonging when they present difficulty and help-seeking as evidence of unsuitability, treat high attrition as proof of academic rigour or imply that successful learners should progress without assistance (Seymour and Hunter, 2019^[90]).

Interventions to address sense of belonging should not seek to encourage learners to become more resilient or confident, as this places responsibility on individuals for conditions that programmes and institutions can change, they need to address structural barriers. Teaching and collaborative learning can strengthen belonging, engagement and academic participation by enabling learners to exchange reasoning, build relationships and make peer support and help-seeking more routine.

Collaborative learning may include problem-solving in pairs, laboratory teams, study groups, design projects, peer instruction and interdisciplinary assignments. Its contribution depends, however, on how activities are designed and facilitated and whether all learners participate meaningfully (Duncan, Holt and Keenan, 2023^[93]; Tharayil et al., 2018^[95]; Hodges, 2018^[96]; Møgelvang and Nyléhn, 2022^[97]). Some learners may dominate discussion, while others may be assigned less visible or peripheral tasks. Research on engineering design teams shows, for example, that gendered task allocation can place women disproportionately in non-technical roles and signal that their technical contributions are less expected or

valued. Masculinised understandings of engineering expertise may also lead women to understate their skills and receive less access to central technical tasks (Schauer et al., 2025^[98]).

Effective collaborative learning requires institutional capacity. Educators need time and expertise to design genuinely interdependent tasks, establish transparent expectations, distribute and monitor responsibilities, support productive interaction and provide constructive and actionable feedback. Assessment should make individual learning and contribution visible alongside the collective output. Programme design, facilitation and assessment should give every learner access to substantive disciplinary and technical reasoning and opportunities to undertake different forms of technical and leadership responsibility.

Gateway courses and assessment can identify learning needs or reinforce exclusion

Gateway courses develop and assess the disciplinary foundations required for later study. Failure in introductory courses can delay progression or lead learners to leave STEM. Where these courses are used to reduce cohort size rather than support learning, they can function as “weeding out” courses (Basu, Malik and Graunke, 2025^[99]; Seymour and Hunter, 2019^[90]). Competitive cultures and certain teaching and assessment practices can then contribute to departure, affecting also learners with strong academic records (Seymour and Hunter, 2019^[90]).

Where substantial numbers of learners encounter the same difficulty, the explanation may not lie solely in their prior preparation. Programme analysis should consider whether prerequisites correspond to the knowledge required, whether core concepts are introduced and practised adequately, whether assessment reflects the stated learning outcomes, and whether curriculum sequencing allows competence to develop progressively. Recurring difficulties in gateway courses should therefore be examined as possible indicators of problems in prerequisites, teaching, assessment or programme design, with diagnostic assessment linked to timely learning support rather than additional selection.

However, when gateway courses are used for development, diagnostic assessment can help learners identify gaps, understand programme expectations and improve their study strategies. It can also show educators where difficulties occur and which learners are affected. Regular, lower-stakes assessment provides opportunities to address problems before a high-stakes examination puts continued participation at risk (Morris, Perry and Wardle, 2021^[100]).

Mentoring relationships are valuable, but quality matters

Mentoring and supportive relationships can help learners interpret academic expectations, respond to setbacks, identify research and professional opportunities and envisage themselves as future members of a field. Contact with peers, academic staff and professionals may provide technical guidance, encouragement and recognition, and access to opportunities beyond the formal programme (McKean et al., 2024^[101]; Ravishankar et al., 2024^[102]).

However, access to and use of these relationships are unevenly distributed among learners. Those who are already connected with academic and professional networks may find mentors and research opportunities informally, while others may have fewer opportunities or less time in which to establish such relationships (Reeves et al., 2022^[103]; Zuckerman, Lo and Juavinett, 2024^[104]; Torres-García, Zamudio-Orozco and Meráz García, 2026^[105]). It requires institutional capacity to organise mentoring at sufficient scale, connect learners with suitable mentors, prepare and support mentors, monitor whether relationships are effective and provide alternative sources of support where necessary.

Financial and practical pressures can interrupt otherwise viable study

Financial and practical pressures can interrupt study even when learners are academically able and committed to continuing. As discussed under Bottleneck 1, costs for fees, accommodation and living, and forgone earnings can affect whether a STEM route remains financially feasible after enrolment. Financial and academic difficulties can reinforce one another. Financial pressure may reduce the time available for

study, while failure in a prerequisite course can lengthen the programme and increase its cost. A temporary loss of income, housing or care arrangements can therefore lead to academic difficulty, and academic delay can create further financial pressure.

Paid employment does not necessarily impede persistence. Its effects depend on the number and predictability of working hours, the learner's circumstances and whether the work is related to the programme. Intensive employment is generally associated with weaker academic outcomes and a greater risk of departure, while relevant work can provide income, professional contacts and opportunities to apply learning (Kocsis, Alter and Pusztai, 2022^[106]; Choi, 2017^[107]).

Part-time study, adaptable schedules, hybrid participation, temporary interruption and structured return can help learners continue during periods of employment, caring responsibilities, illness or other disruption. However, flexible routes may remain difficult to use if required courses are offered infrequently, practical sessions require full-time attendance or part-time learners have less access to projects, research and professional opportunities (El Galad, Betts and Campbell, 2024^[108]).

An interruption does not necessarily indicate a loss of interest or commitment. Learners may stop because of financial difficulties, caring responsibilities or problems in particular courses and later seek to return. Institutions therefore need clear arrangements for interruption, re-entry and guidance rather than treating all interruptions as academic disengagement (West, Chen and Boika, 2024^[109]). Making these arrangements usable requires reliable records of completed learning and learner status, clear responsibility for maintaining proportionate contact during the interruption, and timely academic and practical guidance before return. This can be difficult where learners do not enrol for one or more academic years, particularly if information and responsibilities are fragmented across programme, administrative and support functions.

Institutional capacity determines whether student support is timely, connected and sustainable

Persistence and completion also depend on whether institutions have the capacity to help learners with different preparation and circumstances meet programme standards.

A programme may be difficult to navigate as a whole. Programme leadership is needed to connect courses, co-ordinate teaching and assessment, align support with curriculum requirements and identify recurring barriers to progression (Roehrig et al., 2021^[110]; Frost and Ackrill, 2025^[111]). Staff acting as programme leaders need sufficient time, authority and evidence to improve programme coherence (Aalde and Staal Jensen, 2023^[112]).

Student support includes academic, personal and psychosocial support. The aim is to help learners understand expectations, address difficulties and respond to setbacks, particularly at predictable transition points. Academic support includes tutoring, learning guidance and assistance with course requirements. Personal support helps learners address practical circumstances affecting participation, including financial, administrative, accessibility, health and caring-related needs. Psychosocial support includes counselling and other specialist assistance with well-being, adjustment, relationships and belonging.

Student support needs to be accessible, connected with programme requirements and co-ordinated across academic and specialist services. Fragmented services may require learners to navigate several offices when they have limited time or capacity to do so. Academic programmes and specialist services therefore need clear connections, responsibilities and referral arrangements, while preserving confidentiality and professional boundaries. Staff providing student support need sufficient time and recognition for advising and mentoring (Hofstra et al., 2022^[113]).

Early-warning systems can reveal patterns in performance, participation and credit accumulation, but they are useful only when institutions can understand the causes and provide timely support (Akçapınar, Altun and Aşkar, 2019^[114]); (Rets, Herodotou and Gillespie, 2023^[115]). These systems should be used carefully. Learner data do not explain why difficulties arise, and risk classifications may reproduce inequalities or

label learners. When many learners struggle in the same course or transition, the problem may lie in teaching, assessment, curriculum sequencing or programme organisation. Learning analytics also raise concerns about privacy, transparency, consent, bias and institutional responsibility (Cerratto Pargman and McGrath, 2021^[116]; Tzimas and Demetriadis, 2021^[117]).

Evidence should therefore be examined at both learner and programme levels. It can identify learners who need immediate support and reveal aspects of programme design that require improvement. Responsibility for acting on this evidence is distributed across institutional and disciplinary structures. The Student Assessment of their Learning Gains, developed by Seymour et al. (2000^[118]), was designed for this purpose. It focuses on students' reported gains in understanding, skills, attitudes and the integration of knowledge, rather than general satisfaction with the educator or course.

Implications for diagnosing a persistence and completion bottleneck

Diagnosing a bottleneck in persistence and completion needs to distinguish withdrawal, transfer, temporary interruption, continued enrolment, delayed completion and completion in another programme or field. Transfer or interruption may represent an appropriate change of route rather than a failure to persist. Completion indicators should also be disaggregated by field, programme and population group and interpreted in relation to the observation period and the learners covered. Indicators limited to full-time entrants, for example, do not provide a complete picture where part-time study is common.

Diagnosis requires evidence from learners, programme teams, higher education institutions and public authorities. Learners can provide information on the circumstances and experiences underlying transfer, interruption, delay or withdrawal; programme teams and institutions can identify recurring difficulties in courses, transitions and support arrangements; and public authorities can enable analysis across institutions, education sectors and periods of study. Responsibility for addressing identified constraints lies primarily with higher education institutions and programme leaders, supported by public authorities where constraints concern funding, regulation, system structures or the secure linkage of data.

Diagnosis should identify when and where difficulties arise, whether they are concentrated in particular courses or transition points, and how outcomes differ across programmes and learner groups. Prior preparation needs to be considered alongside programme culture, teaching, assessment, feedback, curriculum sequencing, belonging, collaborative learning, mentoring, financial and practical pressures, flexible study arrangements, access to academic and psychosocial support, and institutional capacity. Differences in completion between fields do not by themselves show whether the causes lie in entrants' preparation, admission arrangements or the conditions encountered within programmes.

Following learners across institutions, education sectors and periods of study is necessary but can be difficult. An institution may record a learner as having withdrawn when the learner has transferred, resumed study elsewhere or subsequently completed another programme. A unique student identifier can support secure linkage of enrolment, credit, transfer and completion records and help distinguish permanent departure from movement, interruption followed by return and completion elsewhere. Its usefulness depends on consistent reporting, data quality, interoperability and clear rules governing access, linkage, privacy and permissible uses. An identifier links records but does not explain why a learner changed route and should therefore be combined with programme-level evidence and information from learners.

Programme culture, belonging and collaborative learning should be examined together as dimensions of programme quality. Evidence should show whether learners feel accepted, supported and recognised; can participate substantively, seek help and receive constructive feedback; and have a reasonable opportunity to recover from setbacks without difficulty being treated as evidence of unsuitability. Analysis should examine classroom climate, interactions with peers and educators, the organisation and facilitation of collaborative work, and whether expectations, responsibilities and assessment criteria are transparent. In collaborative activities, it should determine whether all learners participate in substantive disciplinary and technical reasoning or whether some dominate while others are confined to peripheral or less visible tasks.

It should also assess whether particular groups receive less recognition, have weaker access to informal advice or are given fewer opportunities to undertake technical and leadership responsibilities.

Recurring difficulty in a gateway course may reflect gaps in prior preparation, but it may also indicate misaligned prerequisites, inadequate opportunities to practise, ineffective teaching, unsuitable assessment or problems in curriculum sequencing. Diagnosis should examine whether gateway courses develop and assess the foundations required for later study or function mainly to reduce cohort size. Diagnostic and lower-stakes assessment can help identify difficulties early, but only if it is connected with timely support and a reasonable opportunity to meet transparent academic standards.

Financial and practical pressures should be examined throughout study rather than only at entry. Diagnosis should consider direct costs, living and housing costs, caring responsibilities, health, employment and the time demands of laboratory work, fieldwork, projects and placements. It should also examine how academic and financial difficulties reinforce one another, since failure in a prerequisite course can extend the duration and cost of study, while financial pressure can reduce the time available for learning. Paid employment should not automatically be treated as a barrier: its effects depend on the number and predictability of working hours, the learner's circumstances and whether the work contributes to professional learning.

Flexible study, adaptable schedules, temporary interruption and structured return should be assessed for whether they enable learners to continue or resume study while preserving coherent course sequences, substantive practical and collaborative learning, academic guidance and access to research and professional opportunities. Diagnosis should determine whether apparently flexible routes are usable in practice, including whether required courses are offered sufficiently often and whether practical activities are accessible to part-time learners. Institutions also need reliable records of completed learning and learner status, clear responsibility for proportionate contact during interruption where possible, timely guidance before return and arrangements that allow learners to resume without unnecessary loss of relevant previous learning.

Institutional capacity should be assessed in relation to the scale, timeliness and coherence of teaching and learner support. Effective teaching, practice, formative assessment, feedback, supervised laboratory and project work, academic guidance and psychosocial support depend on sufficient academic and technical staffing, infrastructure and organisational capacity. Diagnosis should examine whether support is accessible and connected with mainstream study or fragmented across services that learners must navigate independently. It should also assess whether academic programmes and specialist services have clear responsibilities and referral arrangements for responding to academic difficulties, financial and personal pressures, discrimination and exclusion, while preserving confidentiality and professional boundaries.

Bottleneck 3: Progression to higher levels of STEM studies

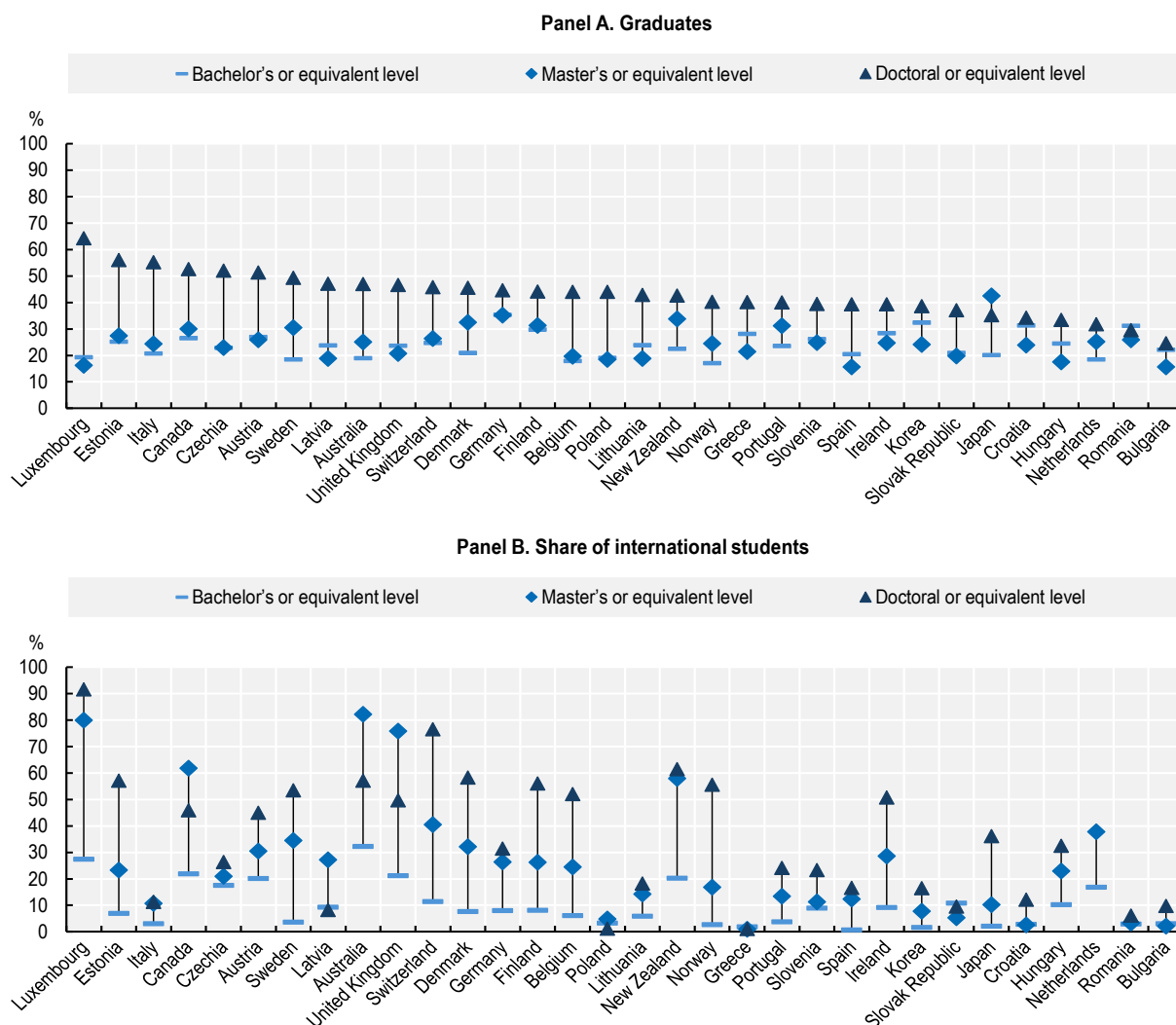
Progression to higher levels in STEM can take several forms and does not necessarily follow a linear sequence. Learners may progress from a short-cycle programme to a bachelor's programme, from bachelor's to master's study, or from master's to doctoral education. They may also enter employment after an earlier qualification and develop advanced STEM skills through professional practice, work-based learning or a later return to education. A progression bottleneck arises when learners with the interest and potential to benefit from advanced study cannot progress because of avoidable academic, financial, informational, geographical or institutional barriers.

Figure 1.6 provides context for examining progression. Panel A presents core STEM graduates as a share of all graduates at each level, while Panel B presents internationally mobile students as a share of core STEM enrolment. The panels have different denominators, do not follow the same learners over time and are not independent, since the graduates in Panel A include internationally mobile graduates. Considering

both indicators together helps assess the relative prominence of core STEM at advanced levels and the extent to which advanced provision draws on domestic and internationally mobile learners.

Figure 1.6. Core STEM representation and international participation vary across tertiary levels and countries

Core STEM graduates as a percentage of all graduates, and internationally mobile students as a percentage of core STEM enrolment, by level of education, 2024



Note: Panel A shows graduates in core STEM as a percentage of all graduates at the level indicated. Panel B shows internationally mobile students as a percentage of all students enrolled in core STEM at the level indicated. The two panels have different denominators and are not independent, since graduate counts in Panel A include internationally mobile graduates. Core STEM comprises natural sciences, mathematics and statistics (ISCED-F 05), information and communication technologies (ISCED-F 06) and engineering, manufacturing and construction (ISCED-F 07). Mobile students are identified on the basis of country of prior education and include nationals of the reporting country who completed their prior education abroad. Countries are ranked in descending order of the core STEM share of doctoral graduates, and the same order is used in both panels. France is not shown, as it does not report the number of international students. Doctoral data on international students are not available for the Netherlands. Values for Graduates in Sweden and Portugal refer to 2023.

Source: OECD (2026^[54]), *Distribution of enrolled students, new entrants and graduates by field of education*, (database), OECD Data Explorer, <https://data-explorer.oecd.org/s/5kw>; OECD (2026^[40]), *Number of enrolled students, graduates and new entrants by field of education*, (database), OECD Data Explorer, <https://data-explorer.oecd.org/s/5ky>.

Core STEM accounts for 24% of bachelor's graduates and 43% of doctoral graduates on average across the countries shown. Its share is higher among doctoral than bachelor's graduates in almost every country, although the difference ranges from 45 percentage points in Luxembourg and 35 percentage points in Italy to three percentage points or less in Croatia and Bulgaria.

The greater representation of core STEM emerges primarily at doctoral level rather than through a steady increase across all three levels. Core STEM accounts for 25% of master's graduates on average, almost the same as its share among bachelor's graduates, and its share is lower among master's than bachelor's graduates in 17 of the 32 countries shown. The difference is particularly pronounced in Korea, where core STEM accounts for 32% of bachelor's graduates but 24% of master's graduates, and is also visible in Croatia, Hungary, Romania and Bulgaria. These cross-sectional differences show how the composition of graduates varies by level, but do not indicate whether individual learners progress from one level to the next.

Internationally mobile students represent larger shares of core STEM enrolment at more advanced levels. Across EU Member States, they account for 8% of core STEM bachelor's enrolment, 21% of master's enrolment and 30% of doctoral enrolment. The largest increase is therefore between bachelor's and master's levels. Australia, the United Kingdom and Canada differ from the general pattern because the international share is highest at master's level, reaching 82%, 76% and 62%, respectively.

Reading the panels together illustrates that countries with similar core STEM shares among doctoral graduates can differ substantially in the international composition of core STEM doctoral enrolment. Italy and Switzerland both record high core STEM shares among doctoral graduates, at 55% and 46% respectively, but internationally mobile students account for 11% of core STEM doctoral enrolment in Italy and 77% in Switzerland. Poland and Greece combine core STEM shares among doctoral graduates of 44% and 40% with international shares of around 1%, while Denmark, Finland, Norway and Belgium record broadly comparable graduate shares alongside international shares above 50%. These comparisons do not establish a relationship between the two indicators, but they show that a similar representation of core STEM among doctoral graduates can be associated with very different patterns of international participation.

International mobility is an important part of the development and circulation of advanced STEM skills. As global competition for learners, researchers and experienced professionals intensifies, countries and higher education institutions may seek to attract international talent, particularly in specialised and emerging fields. The patterns in Figure 1.6 raise different questions for diagnosis. Where internationally mobile students account for a small share of advanced core STEM enrolment, analysis may focus on domestic participation and progression, the availability and attractiveness of advanced study, and institutional capacity. Where the international share is high, analysis should also examine access and support for internationally mobile students, recruitment conditions and the exposure of advanced provision to changes in international mobility. In both cases, diagnosing a progression bottleneck requires learner-level evidence on movement between levels, fields and institutions and on the conditions shaping decisions to continue, change route, enter employment or return to education. Diagnosis should examine attraction, recognition, integration, retention, return and international collaboration as connected parts of mobility, while also considering whether dependence on international recruitment substitutes for investment in domestic talent development or transfers shortages between countries.

For short-cycle programmes to support progression, occupational and educational routes need to be connected

Short-cycle qualifications in post-secondary education generally develop occupation- and industry-specific skills. Their value depends not only on immediate employment outcomes, but also on whether graduates can adapt as technologies, occupations and skills requirements change. Focused preparation may support rapid entry into work but lose value over time if it provides limited foundations for adaptation and further

learning. The initial employment advantage associated with vocational education may therefore decline over working life (Hanushek et al., 2016^[119]).

Evidence on short-cycle post-secondary education needs to be interpreted in context. Much of the empirical literature concerns community colleges and other public two-year institutions in the United States (Soliz, 2023^[120]). Programmes and institutions differ across countries in their duration, admission arrangements, curricular orientation, occupational standing and progression rights (Cavallaro, 2023^[121]). Community colleges, higher technical institutions, universities of applied sciences and dual vocational arrangements should therefore not be treated as interchangeable. Evidence from one model needs to be interpreted in relation to the governance, qualification system, labour market, employer involvement and transfer arrangements of the relevant system (Li and Pilz, 2021^[122]).

Many countries across the OECD area have introduced short-cycle in STEM. Ideally, these programmes should provide credible routes to further study. Not all learners will wish or need to progress immediately, but they should be able to return later to deepen their advanced STEM skills or respond to changing occupational requirements. However, formal progression rights do not always make this possible in practice. Credits may count only as electives rather than towards the sequenced requirements of a bachelor's programme, requiring learners to repeat content, complete additional prerequisites or extend their studies. This creates a bottleneck in progression.

Progression from bachelor's to master's study depends on the value, visibility and accessibility of further specialisation

Bachelor's programmes fulfil a double role as they prepare graduates for employment and provide foundations for master's and doctoral study. The balance between these two functions varies across STEM fields and occupations. A bachelor's degree is sufficient for many occupations, while research-intensive and specialised roles may require or favour an advanced qualification. This varies by field, programme and graduate characteristics (Okahana and Hao, 2019^[123]; Skjelbred and Nesje, 2022^[124]).

Learners need to assess whether a master's qualification is necessary for their intended career, whether a suitable specialisation is available and whether its expected value justifies the additional time, cost and forgone earnings. Some may enter employment, combine work and study or return after gaining professional experience. A bottleneck arises when learners who would benefit from master's study cannot progress because of avoidable barriers rather than an informed decision to follow another route.

Grades influence admission, financial support and access to research opportunities, but they need to be interpreted in context. Applicants may have studied in programmes with different curricula, assessment practices, institutional resources and opportunities for practical or advanced work. Evidence from biomedical sciences indicates that grades and standardised test scores have limited or variable relationships with later doctoral outcomes (Walters et al., 2022^[125]). Holistic admissions approaches seek to consider grades alongside research experience, relevant competence, previous opportunities and programme fit (Young et al., 2022^[126]; Posselt et al., 2023^[127]).

When a master's qualification is a formal or practical requirement for doctoral study in a field, barriers to master's entry and completion can also restrict access to doctoral education. The availability, cost and geographical distribution of suitable master's programmes, together with admission requirements and access to research experience, can therefore shape who is able to pursue a research route.

Undergraduate research can help learners understand how scientific knowledge is produced, develop research skills and decide whether advanced study suits their interests. Experience in laboratory work, course-based research, independent projects or research placements is associated with stronger scientific understanding, confidence and preparation for postgraduate study. It is also associated with persistence and completion, although its causal effects are difficult to establish because participation is not randomly assigned (Seymour et al., 2004^[128]; Lopatto, 2007^[129]; Haeger, Bueno and Sedlacek, 2024^[130]).

Access to research experience and specialised programmes is uneven (Pierszalowski, Bouwma-Gearhart and Marlow, 2021^[131]; Young et al., 2022^[126]; Crumley-Effinger, 2023^[132]; Topliceanu, Blanchard and Collier, 2026^[133]). Learners may lack information or contacts, face informal selection processes or be unable to accept unpaid or poorly paid positions. Opportunities may be concentrated in research-intensive institutions or a limited number of locations. Relocation or international mobility can widen learners' options but introduce costs and barriers related to accommodation, language, immigration requirements and qualification recognition.

Progression across disciplines requires transparent routes

Many scientific and technological developments depend on integrating knowledge and methods from several disciplines. Enabling learners to progress across disciplines can widen access to emerging fields, connect established areas of expertise and support the development of new combinations of advanced STEM skills. Such progression does not replace disciplinary depth: learners need sufficient foundations to understand, evaluate and integrate the contributions of the fields involved.

Progression across disciplines can support the development of advanced STEM skills, especially in emerging fields that combine several disciplines. Quantum technologies draw on physics, mathematics, computing and engineering; data science combines mathematics, statistics, computing and domain knowledge; and robotics connects engineering with control, sensing and AI. Learners may enter these fields by building on one discipline or through an interdisciplinary programme.

A key challenge is to recognise relevant previous learning while ensuring that learners have the foundations required by the new field. Programme titles do not always show the depth developed in each discipline, how the disciplines are integrated or which further study and employment routes the programme supports. Learners and receiving institutions therefore need clear information about assumed prior knowledge, areas of disciplinary depth, the purpose of integration, additional preparation, assessment and progression routes (Mazzeo Ortolani, 2025^[134]). Finding a balance between requirements and bridging is important. Rigid admission requirements may exclude applicants with suitable competence and potential, while admission without adequate foundations or bridge provision may lead to difficulties later in the programme.

Interest and success in doctoral education depends on viable routes and sufficient capacity

A bottleneck arises when qualified and interested candidates cannot progress because funded positions, suitable supervision or research infrastructure are unavailable, or because study and career conditions make participation impractical.

Applicants to doctoral education programmes have different levels of research preparation. Admissions criteria such as grades, publications, references and institutional affiliation may reflect applicants' previous opportunities as well as their competence. Research-oriented master's programmes may include extensive methods training, thesis work and laboratory experience, while professionally oriented programmes may focus on specialised employment. Limited previous research experience should therefore not automatically be interpreted as limited research potential (Young et al., 2022^[126]). More holistic assessment criteria considers academic achievement alongside relevant competence, research experience, prior opportunities and programme fit but requires clear and consistent criteria (Posselt et al., 2023^[127]; Orellana et al., 2025^[135]).

In many STEM fields doctoral studies involve substantial forgone earnings while offering uncertain financial and career returns. However, doctoral education is essential to the renewal of research, innovation and higher education capacity (Ganapati and Ritchie, 2021^[136]). This suggests that doctoral routes should accommodate movement between employment and research. Professional experience can develop advanced STEM skills and generate research questions, but returning candidates may face limited

recognition, unsuitable funding or difficulty combining study with employment and caring responsibilities. Part-time and other flexible routes can widen access, provided they maintain the depth of research training and offer appropriate supervision and support (Gardner and Gopaul, 2012^[137]).

Progression in doctoral studies also depends on institutional capacity. Limited funding, supervision or research infrastructure may restrict admission even when qualified candidates are available. Capacity includes manageable workloads, prepared supervisors, consistent guidance, access to research communities and infrastructure, professional development, and clear procedures for addressing supervisory difficulties (Sherman et al., 2021^[138]; Bahnson and Abane, 2026^[139]; Bach, Armstrong and Jones, 2025^[140]).

Implications for diagnosing a progression bottleneck

Diagnosing a progression bottleneck is challenging. In a nutshell it means that learners who are interested in and could benefit from higher-level study face avoidable barriers to an appropriate route. Available indicators need to be interpreted carefully. Graduate shares at different qualification levels do not track individual movement between levels, while graduate shares and the international composition of enrolment concern different populations.

Diagnosis requires evidence from multiple sources, including learners, programme teams, higher education institutions, employers and public authorities. Learners can provide information on their objectives, decisions and the academic, financial and practical barriers they encounter. Programme teams and higher education institutions can identify constraints related to preparation, admissions, recognition, provision, funding, supervision and research opportunities. Employers can provide evidence on occupational destinations, the value attached to advanced qualifications and opportunities to move between employment and education. Public authorities can enable analysis across institutions, qualification levels and education sectors and identify constraints arising from funding, regulation, recognition systems, geography and international mobility. Responsibility for addressing identified constraints is distributed among these actors according to the route and condition concerned.

Progression should be examined as a connected route rather than as a series of isolated admission decisions. The following are key aspects.

For progression from short-cycle to bachelor's study, diagnosis should examine curriculum alignment, guidance, admission requirements, credit recognition and access to additional preparation. Formal progression rights are insufficient if credits do not meet the sequenced requirements of the receiving programme, learners must unnecessarily repeat previous learning or required courses are inaccessible. Analysis should also reflect differences among national qualification systems, institutional models, labour markets and forms of employer involvement rather than assuming that short-cycle programmes operate similarly across countries.

For progression from bachelor's to master's study, diagnosis should consider the purpose and expected value of further specialisation, the availability of suitable programmes, admission requirements, direct costs, forgone earnings and opportunities to combine study with employment or return later. Entry into employment should not be treated as evidence of constrained progression when a bachelor's qualification provides appropriate preparation for the learner's intended occupation. The relevant question is whether learners who would benefit from master's study can identify, access and finance an appropriate route.

Access to research experience requires particular attention because it can shape learners' understanding of research, development of research competence and preparation for postgraduate study. Laboratory work, course-based research, independent projects and research placements can help learners assess whether postgraduate study suits their interests. Access may nevertheless depend on information, academic contacts, informal selection, institutional location and the ability to accept unpaid or poorly paid opportunities. For doctoral progression, diagnosis should include among others sustainable funding,

supervision capacity, and research infrastructure. Learners also need preparation for careers within and beyond academia (OECD, 2023^[141]).

Progression across fields requires flexible entry combined with adequate foundations. Rigid requirements may exclude applicants with relevant competence and potential, while admission without the required foundations or suitable bridge provision may create difficulties later. Programme titles alone may not indicate disciplinary depth, how knowledge and methods are integrated or which further educational and professional routes are available. Recognition arrangements should reduce unnecessary repetition while preserving the competence required at the receiving level.

Financial, geographical and administrative barriers can affect progression across all routes. Diagnosis should consider tuition and living costs, forgone earnings, relocation and accommodation, the availability of suitable programmes, language and immigration requirements, qualification recognition and the feasibility of combining study with employment or caring responsibilities. International mobility can widen access to specialised provision but can also introduce additional costs and administrative barriers. Where advanced provision depends substantially on internationally mobile learners, analysis should consider their access and participation alongside domestic progression and the exposure of provision to changes in international mobility.

Bottleneck 4: Career entry and effective skills use

A career entry and effective skills use bottleneck arises when people with relevant advanced STEM skills cannot obtain suitable work or use and develop those skills in employment. The availability of suitable work depends partly on the structure and technological intensity of economic and research activity. Countries and regions with fewer research-intensive, capital-intensive or technologically complex organisations may generate less demand for some advanced STEM profiles, while demand may be concentrated in particular sectors, organisations or locations (OECD, 2025^[37]). This does not necessarily indicate a failure of education or recruitment. Diagnosis therefore needs to consider the industrial, research and innovation context alongside the circumstances of individuals and the practices of employers.

Policymakers need to consider two connected groups of constraints affecting career entry and the effective use of advanced STEM skills (Table 1.3). Constraints affecting individuals concern unequal access to substantive professional experience, occupational information, professional networks and suitable employment. Constraints arising on the employer side concern the interpretation and validation of advanced STEM skills, recruitment criteria, onboarding, work organisation, continued development, working conditions and advancement. These constraints can reinforce one another: for example, unequal access to professional experience can limit the evidence candidates can present, while narrow experience requirements can further restrict entry to suitable work.

Table 1.3. Constraints affecting career entry and the effective use of advanced STEM skills

	Constraint	Implication for career entry and effective skills use
Constraints affecting individuals	Unequal access to substantive professional experience	Affects who can develop and demonstrate disciplinary, interdisciplinary, transversal and professional competence before seeking suitable employment.
	Financial, geographical and personal constraints on access to suitable employment	Restricts the range of suitable employment opportunities that individuals can realistically pursue.
	Unequal access to occupational information and professional networks	Affects who can identify suitable roles, understand recruitment requirements and connect advanced STEM skills with relevant occupations and sectors.
Constraints arising on the employer side	Difficulty interpreting and validating advanced STEM skills	Affects whether employers recognise disciplinary, interdisciplinary, transversal and professional competence and accept the available evidence as demonstrating suitability for a role.

	Constraint	Implication for career entry and effective skills use
	Narrow or inappropriate recruitment criteria	Excludes candidates with relevant advanced STEM skills and the foundations needed to learn in the role when they lack directly comparable experience or organisation-specific knowledge.
	Insufficient onboarding	Limits opportunities to acquire the organisation- and sector-specific knowledge needed to apply existing advanced STEM skills effectively in a new role.
	Work organisation limiting the effective use of advanced STEM skills	Restricts opportunities to apply advanced STEM skills through substantive tasks, professional judgement, autonomy and participation in organisational decision making.
	Insufficient opportunities for early-career development	Limits the consolidation and extension of advanced STEM skills through feedback, mentoring, professional learning, increasingly complex work and greater responsibility.
	Working conditions and advancement structures weakening early-career progression and retention	Affect whether workers can accumulate substantive experience, assume increasing responsibility and remain in work that uses and develops their advanced STEM skills.

The policy concern is not only whether graduates find employment, but whether they obtain suitable and sustainable work, apply their advanced STEM skills and gain access to feedback, learning and greater responsibility. Increasing graduate numbers may have limited effects if employers cannot recognise relevant competence, use narrow recruitment criteria or organise work in ways that restrict skills use and development.

Unequal access to substantive professional experience

Professional experience during study is an important bridge between advanced STEM education and suitable employment. It can help learners understand possible roles, make informed employment choices and demonstrate to employers that they can apply disciplinary knowledge in professional settings (Luk and Chan, 2021^[142]).

Access to professional experience during study uneven. Unpaid or poorly paid placements may be impracticable for learners who need paid employment or must meet additional transport, accommodation or dependent-care costs. Existing work and family responsibilities may create further barriers. Access can also depend on institutional and professional networks. Established relationships between selective universities and prestigious employers may give some learners easier access to internships and subsequent employment, while excluding others with comparable potential (Moss-Pech, 2021^[143]). Participation alone does not establish that an experience is accessible or educationally valuable. Outcomes depend on the relevance and quality of the work, the responsibilities assigned, the supervision and feedback provided, and opportunities to connect workplace experience with academic learning. Placements may provide substantive technical and professional work, but they may also consist mainly of routine, administrative or poorly defined tasks (Luk and Chan, 2021^[142]; Vlachopoulos and Pachni Tsitiridou, 2026^[144]; Schneider et al., 2024^[145]). Higher education institutions and employers share responsibility for quality.

Unequal access can have lasting effects because employers may later treat professional experience as evidence of employability (Luk and Chan, 2021^[142]). Learners who obtain substantive placements can strengthen their position in recruitment, while others may appear less prepared even when they have comparable disciplinary foundations and potential. Inequality in access to professional experience during study can therefore reinforce employer-side difficulties in interpreting and validating advanced STEM skills.

Financial, geographical and personal constraints can limit access to suitable employment

Employment outside a person's field of study or below their qualification level may reflect limited access to suitable work rather than a lack of relevant skills or interest. Access depends not only on an individual's qualifications and advanced STEM skills, but also on whether relevant work is available and realistically accessible.

Housing, relocation and transport costs limit where people can work. Low-paid or temporary roles and long recruitment processes may be impractical for those who need a secure income. Caring responsibilities, disability-related needs and immigration conditions may further restrict their options. These constraints are especially important when suitable work is concentrated in particular regions, sectors or organisations. Such concentration may reflect the location of research infrastructure, capital-intensive production, technologically advanced firms, public research organisations or related economic clusters. In regions where these activities are limited, fewer roles may provide opportunities to use and develop particular advanced STEM skills.

Working conditions also shape whether suitable roles are accessible. Temporary contracts, mobility requirements, uncertain progression and long or unpredictable hours may exclude people unable to accept the associated risks. People may choose a more accessible and secure role over one that better matches their qualification but requires relocation, offers insecure income or conflicts with other responsibilities.

Constraints may continue after employment begins. Relocation, irregular hours, extended travel or lower short-term earnings may limit access to specialised experience, research collaboration, substantial technical assignments and greater responsibility. The relevant question is therefore whether people have a viable opportunity to obtain and progress in work that uses and develops their advanced STEM skills.

Unequal access to occupational information and professional networks

Occupational information and professional networks can affect whether individuals identify suitable employment, understand recruitment requirements and connect their advanced STEM skills with different roles and sectors. Information about tasks, working conditions, career prospects and competence requirements may come from programme staff, employers, former placement providers, professional associations, alumni and peers, as well as public vacancy information.

Vacancy descriptions may not explain what the work involves, which requirements are essential, how academic or professional experience will be interpreted, or whether a role offers opportunities to use and develop advanced STEM skills. Programme and occupational labels can be particularly unclear for roles that combine several fields or apply advanced STEM skills outside conventional STEM sectors.

Access to this information and to professional networks is uneven (Moss-Pech, 2021^[143]). Established relationships between selective institutions and employers may give some learners earlier information about opportunities, greater familiarity with recruitment practices and easier access to professional references. Candidates outside these networks may have less contextual support when interpreting requirements and presenting their experience. These differences become especially important where recruitment relies on informal recommendations, knowledge of particular sectors or the ability to present qualifications and experience in forms employers readily recognise.

Furthermore, substantial experience requirements can create a circular barrier: candidates need experience to obtain their first role but cannot gain recognised experience without access to substantive work. Unequal access to placements, professional networks and information can reinforce this problem. Lengthy recruitment, repeated internships, insecure initial employment and mobility requirements may further exclude candidates who cannot absorb the financial or personal costs.

Employers may have difficulty interpreting and validating advanced STEM skills

Employers may find it difficult to judge what applicants' qualifications, skills and experience show about their ability to perform a role. Because employers cannot observe performance before appointment, they often use qualifications, previous experience and other evidence as signals of potential (Spence, 1973^[27]).

The main issue is whether employers can interpret and validate relevant advanced STEM skills without relying unnecessarily on narrow proxies, that is, familiar institutions, employers or directly comparable

experience (Stans et al., 2025^[146]). Particularly difficult to interpret can be interdisciplinary programmes, international qualifications, and movement between fields (Tomlinson and Anderson, 2020^[147]). Work samples, structured technical tasks and competence-based assessment can provide more direct evidence but may increase recruitment costs or disadvantage candidates with fewer opportunities to produce recognised evidence.

Doctoral and interdisciplinary graduates, people moving between fields, international graduates and candidates from less familiar institutions may be especially affected because employers can find their competence harder to interpret (Ganapati and Ritchie, 2021^[136]; Sinche et al., 2017^[148]; Skakni et al., 2025^[149]).

Employers differ in their willingness and capacity to support learning after recruitment

Starting a professional role involves further learning, particularly when advanced STEM skills are concerned. Graduates may have strong disciplinary, analytical and research foundations but still need to learn the organisation's processes, technologies, expectations, regulations and working practices through onboarding. These are not necessarily gaps in higher education because much of this knowledge is specific to the workplace (Mitschelen and Kauffeld, 2025^[150]).

Onboarding typically combines formal training, supervised work, feedback, mentoring and informal learning. Effective onboarding should clarify the role, connect previous learning with workplace tasks, develop organisation- and sector-specific knowledge, explain relevant standards and responsibilities, provide feedback and support, and enable progression towards greater autonomy and responsibility. Weak onboarding can leave employees uncertain about their responsibilities, how to apply their skills and where to seek support. This can delay learning, weaken performance and job satisfaction, and increase intentions to leave (Cingillioglu and Schoettner, 2025^[151]; Bauer et al., 2024^[152]).

Claims that graduates are not sufficiently “work ready” may indicate gaps in education but may also reflect an expectation that they already possess organisation-specific know-how, which requires effective onboarding (OECD, 2021^[153]; OECD, 2026^[154]). Organisations may employ people with advanced STEM skills but lack the expertise, management practices or structures needed to use them effectively. This reflects an organisation's ability to recognise, understand and apply relevant knowledge, often described as its absorptive capacity (Cohen and Levinthal, 1990^[155]). Organisations with low absorptive capacity of advanced STEM skills may struggle to assess employees' skills, design suitable work or support their continued development.

The scope for public policy intervention is limited because employers are primarily responsible for work organisation. Public authorities and intermediary organisations may support management development, knowledge exchange and collaboration, but employers determine whether advanced STEM skills are used through substantive tasks, professional judgement, participation in decisions and progression towards greater responsibility.

Working conditions and advancement structures affect retention

Suitable employment at entry does not ensure that early-career workers can remain, develop and progress. Employment security, pay, working hours, organisational culture and access to significant assignments affect whether they gain experience and move towards greater autonomy and responsibility. This is an area for public policy intervention.

Temporary contracts, uncertain career prospects and mobility requirements can make STEM careers difficult to sustain. These conditions may also limit access to the assignments, relationships and experience through which advanced STEM skills become recognised. In academia, insecure employment is associated with stress, exhaustion and uncertainty (Solomon and Du Plessis, 2023^[156]).

Career paths may diverge after parenthood. Evidence from the United States shows that both mothers and fathers are more likely to leave full-time STEM employment after becoming parents, but departures are more common among mothers. Women are also more likely to move to part-time work or leave employment altogether (Cech and Blair-Loy, 2014^[157]). Similar differences are found in progression to permanent academic positions (Lassen and Ivandić, 2024^[158]).

Implications for diagnosing a career entry and effective skills use bottleneck

Diagnosing a career entry and effective skills use bottleneck requires more than employment rates, qualification matching and occupational classifications. Relevant opportunities may be concentrated in particular sectors, organisations and regions and depend on the economic, research and innovation structure of a country or region.

Multiple sources of evidence are needed for diagnosis. Individuals can describe their access to opportunities, recruitment experiences, work and development; employers can provide evidence on competence requirements and employment practices; and institutions and public authorities can identify patterns across programmes, sectors, regions and population groups. Responsibility depends on the constraint concerned, although employers are primarily responsible for recruitment and for the conditions under which advanced STEM skills are used and developed at work.

The following are key aspects of diagnosing a bottleneck in career entry and effective use of advanced STEM skills.

Financial, geographical and personal circumstances may restrict the placements and roles that individuals can realistically pursue. Relevant constraints may include unpaid or poorly paid opportunities, transport and relocation costs, limited availability of suitable housing, dependent care, disability-related requirements, immigration conditions, insecure employment and lengthy recruitment processes.

Where professional experience is organised as part of a study programme, it should be assessed for its substance and quality, not simply by whether learners participated. Diagnosis should examine the relevance and complexity of the work, the technical and professional responsibilities assigned, the supervision and feedback provided, and the connection with academic learning. It should determine whether placements enable learners to develop and demonstrate disciplinary, interdisciplinary, transversal and professional competence. Evidence should also show who gains access to meaningful projects, references and work samples that employers subsequently recognise, since unequal access to these opportunities can produce unequal credibility during recruitment.

Employer recruitment practices should be examined alongside candidate supply. Recruitment difficulties may indicate that relevant competence is unavailable, but they may also reflect difficulty interpreting evidence of advanced STEM skills, narrow selection criteria or requirements for directly comparable experience. Policymakers have an interest in distinguishing among these causes because treating all recruitment difficulties as shortages may lead to expanding education provision when the constraint lies in how employers identify, assess or recruit candidates. Better diagnosis can help direct policy towards the relevant constraint and connect investment in advanced STEM skills more effectively with their use in the economy.

Diagnosis should examine whether employers can interpret qualifications, grades, projects, work samples and previous employment in relation to the role concerned. Programme titles alone may not indicate disciplinary depth, how knowledge and methods are integrated or how learning has been applied. Access to recognised projects, professional experience and references is also unequally distributed. Improving how this evidence is interpreted can help employers widen the pool of suitable candidates, reduce reliance on familiar but imperfect proxies and improve the match between candidates' advanced STEM skills and the work they will perform.

Diagnosis should then examine the work employees actually perform rather than relying on occupational titles or qualification requirements. Relevant evidence includes task complexity and variety, access to suitable technologies and infrastructure, autonomy, professional judgement, collaboration across fields, participation in decisions and opportunities for technical expertise to influence organisational practice. Limited use of advanced STEM skills may reflect organisational or managerial constraints rather than insufficient employee competence. Examining skills use can show employers whether recruitment investments translate into performance and organisational learning and help policymakers distinguish insufficient skills supply from limited opportunities to apply available skills effectively within organisations.

Working conditions and advancement structures should be considered integral to skills use, development and retention. Diagnosis should examine pay, employment security, working hours, mobility expectations, organisational culture, professional networks and transparent advancement criteria. It should assess whether parental leave and flexible working can be used without reducing access to promotion or substantive work, and whether discrimination, harassment or exclusion affect development and retention. Organisations may recruit workers with relevant advanced STEM skills but fail to retain them if working conditions, advancement structures or access to suitable work remain inadequate. Diagnosing these conditions can reveal avoidable losses of workers and accumulated experience that might otherwise be interpreted as insufficient external supply.

Bottleneck 5: Skills renewal and return to higher education

Technological change has been altering tasks within occupations and the competence required to perform them (Frey and Osborne, 2017^[159]). For example, AI, robotics and automation have already replaced some tasks and created others making skills renewal an essential part of the development of advanced STEM skills (Gmyrek et al., 2025^[160]).

In this report, skills renewal covers updating or deepening advanced STEM skills in an existing field or role, moving into an adjacent field, such as from engineering to robotics or from mathematics to data science, and preparing for a more substantial occupational change. These forms may overlap, but they require learning of different depth and duration. Updating may involve a short, specialised course, while movement into another field or occupation may require additional foundations and a longer, coherent sequence of learning rather than disconnected courses (Li, 2022^[161]). Skills renewal can take place through continuing education, workplace learning, professional training and other structured learning. Higher education has a distinctive role when learners need advanced disciplinary knowledge, research-informed teaching, specialist infrastructure, credible assessment or supervised work on complex problems. Access may nevertheless remain difficult when programmes and support services are designed mainly for recent school-leavers studying full time.

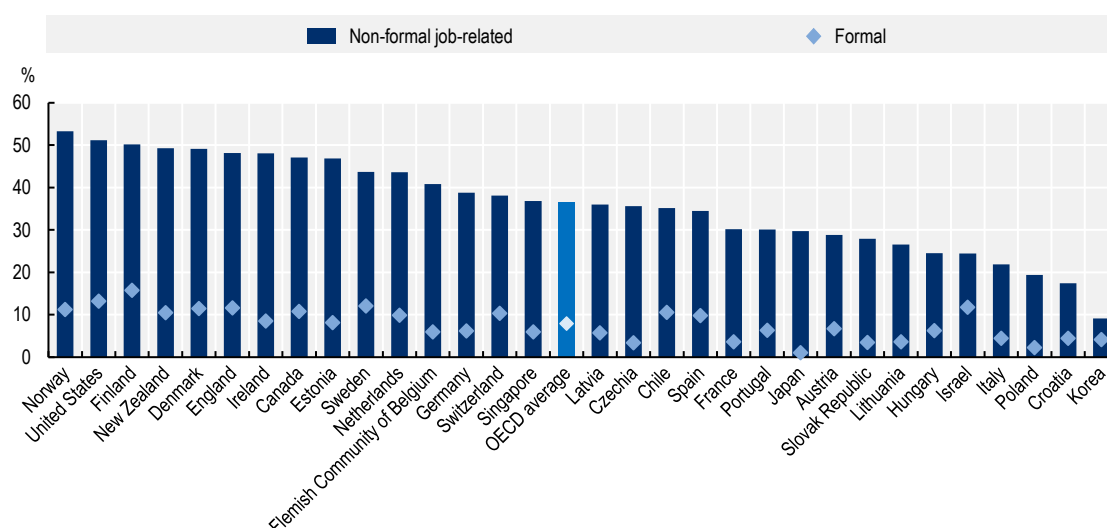
A skills-renewal bottleneck arises when people cannot access or complete the learning needed to update, deepen or extend their skills, or when they cannot apply the renewed skills at work. Responsibilities are shared but differentiated. Public authorities can support accessible provision, finance, information, quality assurance and recognition, while higher education institutions and other providers are responsible for coherent learning and credible assessment. Employers influence whether workers have the time, financial support and flexibility to participate, whether renewed competence is recognised, and whether work provides opportunities to apply and continue developing it. Addressing a skills-renewal bottleneck may consequently require connected action across education and employment rather than provision of additional learning opportunities alone.

Participation in adult learning differs substantially across countries (Figure 1.7). Participation in non-formal, job-related learning ranges from less than 10% in Korea to more than 50% in Norway, compared with an OECD average of approximately 37%. Formal learning generally involves fewer than 15% of adults. Most adult learning therefore takes place through non-formal, job-related provision rather than through a return to formal education. Expanding higher education provision alone is unlikely to remove a skills-renewal

bottleneck. Diagnosis should also consider employer-provided learning, professional and specialist provision, and whether adults have the time, resources and support needed to participate.

Figure 1.7. Adult learning participation varies across countries and is concentrated in non-formal job-related learning

Share of adults who participated in formal or non-formal job-related learning in the 12 months prior to the survey, %



Note: Adults aged 25-65. OECD is an unweighted average of all participating member countries. See source's Box 1.1 for a precise definition of job-related adult learning.

Source: OECD (2025^[162]) Trends in Adult Learning: New Data from the 2023 Survey of Adult Skills, <https://doi.org/10.1787/ec0624a6-en>.

StatLink  <https://stat.link/bznyx9>

Skills renewal depends on provision that meets different learning needs

Adults seeking to develop advanced STEM skills differ in their prior education, professional experience, existing competence and goals.

Four broad groups of learners in skills renewal can be distinguished:

- recent STEM graduates seeking to update or deepen specialist competence
- STEM professionals moving into an adjacent field
- graduates and professionals seeking to move into STEM from another field
- professionals without previous higher education seeking to develop advanced STEM skills

These groups need different routes for skills renewal. A course for experienced STEM professionals may be unsuitable for someone entering from another field, while requiring experienced professionals to repeat extensive foundational learning may add unnecessary time and cost. Adults without previous higher education may need recognition of vocational and workplace learning, support to develop missing foundations and a clear route towards a higher education qualification.

The appropriate provision depends on the purpose of skills renewal. Focused updating may require a short, specialised course. Deeper specialisation, movement into an adjacent field or substantial occupational change may require additional foundations and a longer, coherent sequence of learning. Higher education has a distinctive role where learners need advanced disciplinary knowledge, research-informed content,

specialist infrastructure, formal assessment or a recognised qualification. Employers, professional bodies and specialist providers may be better placed to address changes in particular tools, standards and workplace practices.

Cost, time, caring responsibilities, location, scheduling and limited employer support may prevent participation. Learning may also be constrained by missing foundations, weak sequencing, limited access to specialist educators or infrastructure, insufficient feedback and few opportunities to apply learning to complex problems (OECD, 2025^[163]). These constraints may reinforce one another. Adults who need additional preparation or support may also find it difficult to reduce their working hours or attend courses during the working day (Radovan, 2024^[164]; Park and Su, 2026^[165]). Flexible schedules and evening, hybrid, online, modular or part-time provision can help address these constraints by making learning more compatible with employment, caring responsibilities and geographical constraints. However, flexibility alone does not ensure effective learning.

Short learning supports skills renewal only when it is coherent, recognised and sustainable

Micro-credentials have huge potential in skills renewal (OECD, 2023^[166]). They certify specific competence developed through short, targeted learning and are increasingly used to respond to technological and labour-market change and are generally intended to complement rather than replace larger qualifications (OECD, 2023^[166]). Their main advantage is responsiveness. Micro-credentials can help learners acquire current and specialised knowledge in areas such as digital technologies, engineering and green innovation.

However, for advanced STEM skills development short learning provides only a partial response. A short course may update or extend existing advanced STEM skills but cannot compensate for missing foundations. A stand-alone micro-credential may be appropriate for focused updating, while connected components may support deeper specialisation or movement into an adjacent field. More substantial occupational change will generally require additional foundations and a longer, coherent sequence of learning. Where micro-credentials are intended to accumulate towards a larger qualification, their value depends on how they are connected with wider education and training systems (Toledo-Navarrete et al., 2026^[167]).

Public policy can establish common information requirements, quality-assurance arrangements and frameworks for recognition and accumulation. It can also support co-ordination among providers, qualification authorities and employers. Education providers remain responsible for coherent learning and credible assessment, while receiving institutions and employers determine whether credentials are recognised for further study or employment. Without coherent recognition arrangements, learners may complete several useful courses without developing, or being able to demonstrate, the combination of competence required for advanced study or a new professional role (Varadarajan, Koh and Daniel, 2023^[168]; Tamoliune et al., 2023^[169]; OECD, 2026^[170]).

Recognition is still uneven across providers, institutions and labour markets (Gauthier, 2020^[171]; Kässi and Lehdonvirta, 2022^[172]). OECD reviews (e.g. (OECD, 2026^[170]) of micro-credential systems suggest that an accumulation route towards a larger qualification should specify:

- the previous learning required for entry
- the level and volume of each component
- the learning outcomes and assessment
- how the components relate to one another
- which combinations can count towards a larger qualification
- who is responsible for recognition
- whether recognition is automatic or individually assessed
- which further educational or occupational opportunities follow

Implications for diagnosing a skills-renewal bottleneck

Diagnosing a skills-renewal bottleneck requires evidence on whether adults can access suitable learning and develop, demonstrate, apply and gain recognition for the intended advanced STEM skills. Low participation may reflect limited interest among potential learners, but may also arise from unsuitable provision, cost, time, caring responsibilities, location, scheduling or limited employer support. Participation and completion rates therefore need to be interpreted alongside evidence on learning and its subsequent recognition and application. Indicators should distinguish different forms and purposes of learning and, where possible, examine participation and outcomes across fields, learner groups and employment situations.

The following are key aspects in diagnosing a skills-renewal bottleneck.

Diagnosis should first identify the purpose for which skills renewal is needed, the intended learners, their starting points and the educational or occupational outcomes the provision is expected to support. Updating or deepening advanced STEM skills in an existing field, moving into an adjacent field and preparing for substantial occupational change require learning of different depth, duration and coherence. Differences in previous education, professional experience and existing competence also affect the provision required. A short, specialised course may meet a focused updating need, while movement into another field or occupation may require additional foundations and a longer, coherently sequenced route.

Diagnosis should also consider which provider or combination of providers is appropriate for the learning need. Higher education has a distinctive role where learners require advanced disciplinary knowledge, research-informed teaching, specialist infrastructure, credible assessment, supervised work on complex problems or a recognised qualification. Employers, professional bodies and specialist providers may be better placed to address changes in particular tools, standards and workplace practices. Expanding higher education provision alone is therefore unlikely to address all skills-renewal constraints.

Information should be assessed for whether it enables learners seeking skills renewal to understand the prior knowledge required, the purpose and level of the learning, the competence developed and assessed, and the routes available after completion. Where learners combine components from several providers, analysis should examine whether information explains how those components relate, whether they can contribute to a larger qualification, who is responsible for recognition and how education institutions and employers are likely to interpret them. It should also determine whether learners must construct their own routes from fragmented information and uncertain recognition arrangements.

Short courses and micro-credentials may meet focused updating needs, but they should not be assumed to provide the foundations or coherence required for deeper specialisation, movement into an adjacent field or substantial occupational change. Diagnosis should examine whether their scale, content and assessment correspond to the competence required for the intended destination. Where components are intended to accumulate towards a larger qualification, analysis should also consider their entry requirements, level and volume, relationships with one another, recognised combinations and subsequent opportunities. Responsibilities and procedures for recognition should be clear, and accumulation should represent a coherent progression in learning rather than simply the completion of several separate components. Diagnosis should establish whether the provision addresses an identified skills-renewal need, is recognised and sustainable, and supports meaningful educational or occupational progression.

Diagnostic assessment and recognition arrangements should be examined for whether they identify relevant competence developed through education, vocational learning and professional experience, the essential gaps that remain and what can be developed during the programme. Analysis should assess whether recognition reduces unnecessary repetition without removing the disciplinary, interdisciplinary, transversal or professional competence required for successful learning and subsequent practice. For adults without previous higher education, diagnosis should examine whether substantial professional

learning is recognised and whether they can access the foundations required for an advanced STEM qualification.

Financial and practical barriers should be examined in combination. Diagnosis should consider tuition and participation costs, forgone earnings, the feasibility of reducing working hours, caring responsibilities, location, scheduling and access to specialist facilities. It should also examine whether employer support is available across occupations, organisations and forms of employment. Adults who need additional preparation or support may face longer and more costly routes while also having the least flexibility to reduce employment or attend provision during the working day.

Flexible schedules and evening, hybrid, online, modular or part-time provision can widen participation, but flexibility does not itself establish accessibility or quality. Diagnosis should assess whether these formats preserve coherent sequencing, access to specialist educators, timely feedback, credible assessment and learner support. Where advanced STEM learning requires laboratories, software, equipment, data environments, collaborative problem-solving or sustained participation in a disciplinary community, analysis should determine whether learners can access these opportunities in practice.

The opportunity to apply learning is part of skills renewal. Diagnosis should follow learners beyond participation and completion to examine whether they develop demonstrable advanced STEM skills, gain recognition for them and apply them in further education or work. Relevant evidence includes changes in tasks and responsibilities, access to suitable technologies and infrastructure, recognition by managers and colleagues, progression to more complex work and movement towards the intended educational or occupational destination. Analysis should assess employer support not only in terms of time and financial assistance for participation, but also in terms of opportunities to apply and further develop the competence acquired. Monitoring should also examine the level and coherence of the learning, the credibility of assessment and whether learners receive the teaching, support, infrastructure and practical experience needed to achieve the intended outcomes.

Conclusion

Advanced STEM skills combine disciplinary, interdisciplinary, transversal and professional competence and are developed, demonstrated, used and renewed across education, research and employment. The five bottlenecks examined in this chapter identify connected points at which their development and effective use may be constrained: entry into STEM higher education; persistence and completion; progression to advanced levels; career entry and effective skills use; and skills renewal across working life. These bottlenecks are neither independent nor strictly sequential. A constraint may originate before the point at which it becomes visible, affect several transitions or be transferred to a later point. Increasing entry without sufficient teaching and learner support, for example, may weaken persistence and completion, while increasing graduate supply without suitable employment, effective onboarding and substantive work may lead to the underuse of advanced STEM skills.

Broadening the talent base is part of this challenge. It requires systemic barriers in education and work to be addressed so that access to the conditions through which advanced STEM skills are developed and demonstrated does not depend unnecessarily on learners' circumstances. A broader talent base can increase the competence on which employers, research organisations and wider society can draw and bring a wider range of perspectives to STEM education, research, innovation and professional practice.

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2 Setting priorities in advanced STEM skills development

This chapter presents four possible policy priorities for strengthening the development and effective use of advanced science, technology, engineering and mathematics (STEM) skills. It examines measures to enable entry, persistence and completion in STEM higher education; support progression to advanced levels of study and skills renewal across working life; renew STEM programmes around disciplinary, interdisciplinary, transversal and professional competence; and improve career entry and the effective use of advanced STEM skills. Drawing on policy and institutional examples, the chapter considers the rationale for public intervention, intended outcomes, implementation conditions and unintended consequences.

Key issues

A bottleneck becomes a policy priority when evidence identifies a significant and avoidable constraint that public action can help address. The same observed problem may have different causes across fields, places and among groups facing different circumstances or barriers. Policymakers therefore need to identify the mechanism involved, determine which actors can influence it and assess whether they have the resources and capacity to act.

Enabling entry, persistence and completion can broaden the talent base without lowering academic standards. Barriers in preparation, guidance, finance, teaching and programme organisation can prevent learners from entering and completing STEM higher education. Policy intervention can improve access and support institutional capacity. However, any expansion in entry needs sufficient higher education capacity to maintain quality.

Clear and accessible routes can enable more people to progress to advanced study. Progression need not be linear: people may move between education and employment, return to study later or move across fields. Unclear requirements, limited recognition of previous learning, unequal access to research experience and financial or geographical barriers can prevent these movements.

Complex technological and societal problems require programmes that connect STEM disciplines and integrate non-STEM fields. Programme renewal can create these connections and keep learning relevant as knowledge and needs change. It needs to preserve disciplinary depth, ensure meaningful integration rather than superficial exposure, and develop interdisciplinary, transversal and professional competence through aligned teaching and assessment.

Advanced STEM skills create value only when people can apply and continue to develop them at work. Unequal access to professional experience, narrow recruitment criteria, weak onboarding and limited opportunities for substantive work can leave relevant skills unused. Public policy can support paid experience, provide competence frameworks and enhance collaboration between higher education institutions and employers.

Coherent skills-renewal routes can help workers respond to changes in technology, knowledge and professional practice. Higher education has a key role where skills renewal requires advanced disciplinary foundations, research-informed teaching, specialist infrastructure or a recognised qualification. Employers remain responsible for enabling participation and providing opportunities to apply and continue developing advanced STEM skills at work.

From bottlenecks to policy priorities

Identifying a bottleneck is the first step in setting a policy priority. Policymakers need to determine its causes, location and affected groups, whether public action is justified, and which actors have the instruments and capacity to respond. Involving relevant stakeholders can help translate this diagnosis into a coherent set of interventions.

A policy priority is thus context specific. Countries differ in their education systems, demographic conditions, industrial and occupational structures, institutional capacity and existing policy arrangements. The same bottleneck may be widespread in one country, concentrated in a particular region or field in another, and largely absent in a third. Even within one country, the relevant constraint may differ across institutions, qualification levels and population groups. A national priority may therefore require differentiated regional or field-specific responses, while an issue visible in a particular institution or sector

may not justify system-wide intervention. Priorities may also change as patterns of participation, knowledge, technology, labour demand and institutional capacity evolve.

Several of the priorities are relevant to STEM education more generally. They are examined here because advanced STEM skills depend on cumulative development: learners need strong foundations before they can reach greater disciplinary depth, integrate knowledge across fields and exercise advanced professional judgement.

Four policy priorities, each with sub-priorities, are examined in this chapter:

1. Enable entry, persistence and completion in high-quality STEM higher education.
2. Enable progression to advanced STEM expertise and skills renewal across working life.
3. Renew STEM programmes and develop interdisciplinary, STEAM and broadly applicable STEM capabilities.
4. Improve career entry and the effective use and continued development of advanced STEM skills.

Each priority begins by setting out its policy rationale, that is, why public policy should intervene, what are intended outcomes and potential unintended consequences. Policy and institutional examples from different countries and settings are analysed to illustrate these. The examples were selected to cover different bottlenecks, policy instruments, institutional settings and distributions of responsibility among public authorities, higher education institutions, employers and other actors. They are illustrative and should not be interpreted as representative of all activity in a country or as evidence that an approach will produce the same results in every context.

The selection and interpretation of the examples draw on literature review, desk-based analysis and structured discussions in the Mutual Learning Group on Advanced STEM Skills in Higher Education, organised by the OECD Secretariat (Annex A). Members presented policy and institutional initiatives using a common framework covering their rationale and context, the role of public policy, required resources, governance, monitoring and evaluation, and available evidence on impact, equity, sustainability, scalability and transferability. Presentations and supporting material were followed by plenary and breakout discussions comparing implementation conditions across countries and settings. The report's authors supplemented these initiatives with other examples where the literature or the group's discussions identified particular aspects requiring further illustration.

The Mutual Learning Group provided a lens for interpreting the examples in relation to policy relevance, implementation requirements and applicability across contexts. Discussions helped distinguish formal policy or programme design from how an initiative operated in practice and drew attention to conditions that may be less visible in published descriptions or evaluations. These included fragmented responsibilities, limited staff time, unstable funding, difficulties in co-ordinating actors and the practical limits of transferring an approach between systems or institutions. The dialogue also helped identify differences between components that may be adapted and conditions that are essential to an initiative's operation.

Policy evaluation can be difficult because interventions often combine several measures, vary across settings and are influenced by wider changes. Participants may differ from non-participants, suitable comparison groups may be unavailable, and important outcomes may take years to emerge or be difficult to measure. Chapter 3 examines how monitoring, evaluation and comparison across settings can help policymakers understand what works, for whom and under which conditions, and adapt interventions over time.

These considerations inform the discussion of policy priorities, application examples and potential trade-offs throughout this chapter. Table 2.1 provides an overview of the four priorities and their sub-priorities.

Table 2.1. Policy priorities for developing and effectively using advanced STEM skills

Policy priority	Sub-priorities	Why this might be a policy priority	Potential risks and trade-offs
1. Enable entry, persistence and completion in STEM education	<p>1.1 Prepare and guide learners towards entry or re-entry to an initial STEM higher education route.</p> <p>1.2 Strengthen teaching, assessment, belonging and programme coherence to support persistence and completion.</p> <p>1.3 Support financial feasibility, flexible continuation, transfer, interruption, re-entry and completion.</p>	Participation in STEM higher education may be insufficient or unequal, with avoidable barriers in preparation, guidance, finance or programme provision restricting entry and completion.	<p>Increasing entry without sufficient teaching, infrastructure and learner support may shift the constraint to persistence and completion.</p> <p>Flexible routes or additional support may become fragmented, difficult to use or poorly connected to mainstream programmes.</p>
2. Enable progression to advanced STEM expertise and skills renewal	<p>2.1 Make progression between educational levels and fields transparent and usable.</p> <p>2.2 Widen equitable access to research experience and advanced STEM study.</p> <p>2.3 Provide coherent skills-renewal routes through higher education.</p>	Progression or skills renewal may be restricted by unclear requirements, limited recognition of prior learning, unequal access to research experience, and financial, geographical or institutional barriers.	<p>Expanding advanced study without sufficient funding, supervision and infrastructure may weaken quality or delay completion.</p> <p>Flexible or short-form provision may fragment learning without appropriate foundations, coherence and recognition.</p>
3. Renew STEM programmes	<p>3.1 Support interdisciplinary STEM programmes.</p> <p>3.2 Integrate STEM and non-STEM disciplines.</p>	Programmes may need renewal to reflect changes in knowledge, technology, professional practice and societal needs, and to combine disciplinary, interdisciplinary, transversal and professional competence.	<p>External contributions may narrow programmes around immediate organisational or technological requirements unless higher education institutions preserve durable foundations, programme coherence, academic independence and portable learning.</p> <p>Programme renewal may exceed available educator and organisational capacity or infrastructure.</p> <p>Employers may have difficulties recognising skills developed in new programmes.</p>
4. Improve career entry and the effective use and continued development of advanced STEM skills	4.1 Support employers to recognise, recruit, use and continue developing advanced STEM skills effectively.	<p>Graduates with relevant advanced STEM skills have difficulties accessing suitable work, while employer practices may limit how those skills are recognised, recruited, used and further developed.</p> <p>The role of public policy is limited, but Limited role of policy, but university-employer collaboration can improve skills recognition.</p>	<p>Access may remain unequal or geographically concentrated.</p> <p>Placements or entry-level roles may provide routine rather than substantive work.</p> <p>Problems will persist if the barrier is in the recognition and effective use of advanced STEM skills.</p>

Implementing these priorities requires co-ordination across policy portfolios and collaboration among education institutions, employers, research organisations and professional bodies. Each actor has distinct responsibilities, and the form of collaboration will vary across priorities and contexts.

Public authorities can establish enabling frameworks, finance activities with wider public benefits and address barriers that institutions or employers cannot resolve alone. School education policy influences access to the subjects, teaching and guidance that prepare learners for STEM higher education. Vocational education and training and higher education authorities share responsibility for enabling transparent transitions from VET into higher education through clear entry requirements, recognition of relevant previous learning and access to any additional preparation required.

Higher education institutions remain responsible for admission and recognition decisions, curricula, teaching, assessment, learner support and qualification standards. Employers, research organisations, professional bodies and other partners can contribute occupational knowledge, specialist expertise, facilities, funding, authentic projects, and research and professional experience. Their involvement can support programme renewal and strengthen connections between education and professional practice, while higher education institutions retain responsibility for the coherence, standards and academic integrity of qualifications. Employers are responsible for recruitment, onboarding, work organisation, working conditions and employees' continued skills development. National or regional STEM strategies can help align these responsibilities around shared priorities, resources and implementation arrangements (see Chapter 3).

Policy Priority 1. Enable entry, persistence and completion in STEM education

Entry, persistence and completion can become a policy priority where advanced STEM skills are needed, and the supply of graduates is insufficient. Entry depends on preparation, information, perceived relevance and whether study is financially and practically feasible. Persistence and completion depend on teaching, assessment, belonging, learner support and institutional capacity. Increasing entry without strengthening these conditions may move the bottleneck from admission to completion. These outcomes are distinct but connected.

Some of the conditions affecting entry and persistence arise before higher education. Access to mathematics and science, teaching quality, guidance and earlier educational choices affect learners' preparation and eligibility. Financial circumstances, family, friends and social expectations, accessibility and geography all influence whether learners can enter and progress in STEM study.

Routes towards completion need to be continuous. Learners may transfer, interrupt and return, change fields or complete a qualification after a period in employment. Institutions need to preserve relevant previous learning and provide clear routes towards completion. Monitoring should therefore distinguish permanent withdrawal from transfer, interruption, delayed completion and completion elsewhere.

The following sub-priorities focus on:

- preparation and guidance for entry
- teaching, assessment, belonging and programme coherence
- financial support and flexible routes for continuation, transfer, interruption, re-entry and completion

1.1 Prepare and guide learners towards entry to an initial STEM higher education route

Policy rationale, intended outcomes and risks

Entry or re-entry to STEM higher education depends on preparation, information and whether learners can meet the academic, financial and practical requirements. Public policy has a role where access to these conditions is unequal, or fragmented responsibilities lead to a bottleneck in entry as discussed in Chapter 1.

Learners entering from different educational systems, vocational routes or periods away from education may require additional preparation. Necessary academic requirements need to remain in place, but learners need clear and accessible ways to meet them. Foundation years, bridge courses and refresher provision therefore require clear outcomes, appropriate assessment and recognised links to admission.

Formal eligibility does not make a route accessible. Costs, location, disability-related barriers, unsuitable schedules, complex procedures, limited recognition of previous learning and shortages of places may still

prevent entry. Admission, preparation and transition arrangements need to work for learners entering through different routes.

The intended outcome is informed and attainable entry or re-entry for learners with the interest and potential to succeed. Monitoring should cover access to preparation and guidance, application, admission, enrolment and early progress, including differences across learner groups and routes. The main risk is that measures address individual stages without creating a usable route into higher education. For example, outreach may raise expectations without removing barriers, information may explain requirements without helping learners meet them, and assessment may identify gaps without connecting learners with accessible preparation.

Examples of interventions

Effective policy connects guidance, preparation, admission and transition support. Any increase in entry also requires sufficient teaching, infrastructure and learner support to maintain quality and enable persistence and completion. Table 2.2 presents five connected approaches to making entry or re-entry to an initial STEM higher education route informed and attainable.

These approaches are complementary, and effective routes into STEM higher education may require several constraints to be addressed together. The examples show how strong educational foundations can be combined with practical STEM experiences, sustained guidance, mentoring, diagnostic assessment and targeted preparation.

Table 2.2. Selected interventions to prepare and guide learners towards entry to STEM higher education

Approach	Examples	Principal policy contribution
1. Strengthening the foundations for STEM participation	Innovationen Machen Schulen Top (Innovations Make Schools Top), Austria; LUMA Centre Finland – luonnontieteet ja matematiikka (natural sciences and mathematics); Engineering Academy, Estonia	Improve teaching, curriculum, school leadership, infrastructure and collaboration across schools, vocational education and higher education.
2. Widening access to substantive STEM experiences	Actua, Canada; Informatik-Werkstatt (Computing Science Workshop), Austria; Girls to Technical Universities! and Girls into Science!, Poland	Give learners practical and sustained opportunities to explore STEM fields and engage with higher education institutions, current learners and professionals.
3. Strengthening relevance and belonging	STEM Passport for Inclusion, Ireland; Swiss Tecladies; ADA and Diary of a Female Computer Scientist, Austria; Diversity in STEM toolkit and Australian Superstars, Australia; Cultural Collisions and Circus of Knowledge, Austria	Connect STEM with practical experiences and societal purposes through practical participation, sustained relationships, mentoring and visible role models.
4. Supporting informed choice and transition into higher education	Studienplattform.at (Austrian Study Platform) and Studieren Probieren (Try Studying), Austria; BeFirst!, Austria; Studienkompass, Germany	Combine comparable information, direct experience and sustained guidance across programme choice, application, entry and initial participation.
5. Using diagnostic assessment to identify and address preparation needs	Scientific Degree Plan, Italy; calibration and start tests, Flanders	Make programme expectations visible and connect identified preparation needs with accessible learning, tutoring and routes to admission.

1. Strengthening the foundations for STEM participation

Teacher expertise, curriculum, school leadership and access to appropriate learning environments shape whether learners develop the interest, preparation and formal eligibility required for STEM higher education. Access to relevant subjects and the conditions for learning differs across education systems, schools, places and learner groups.

Austria's IMST initiative, "*Innovationen Machen Schulen Top*" (Innovations Make Schools Top), illustrates a school- and system-development approach. Established in 1998 in response to concerns about mathematics and science teaching, it subsequently expanded from upper-secondary education to the wider secondary sector and primary education. IMST combines teacher professional learning, subject-didactics research, regional and thematic networks, teaching materials and support for school-based innovation. It treats school leadership and organisational development, as well as individual teacher competence, as conditions for sustained improvement in teaching (Austrian government, n.d.^[1]; IMST, 2025^[2]).

In its current phase, IMST supports Austria's trial of STEM-focused lower-secondary schools, introduced in 57 selected schools in the 2022/23 academic year. STEM is taught as an interdisciplinary and project-oriented subject supported by a dedicated curriculum and additional teaching time. The initiative shows how public policy can connect curriculum, teacher development, school leadership and professional networks rather than rely on isolated classroom activities. Its longer-term contribution will depend on whether changes in teaching strengthen preparation, subject choice and subsequent participation across different learner groups.

Finland's LUMA Centre illustrates how universities can provide expertise and infrastructure to schools. Under a national task assigned by the Ministry of Education and Culture for the period of 2025-28, LUMA Centre Finland connects 11 universities and 13 regional centres with schools, teachers, families, working-life organisations and non-formal education partners (LUMA Centre Finland, n.d.^[3]; Akela, Lundell and Ikävalko, 2020^[4]).

The network provides university-based and online study visits, science clubs and camps, open teaching materials, teacher professional development and access to laboratory equipment, digital tools, educational games and activity packages. University laboratories serve as teaching, outreach and research environments connecting science departments and teacher education with schools. In 2025, the network reported reaching 87% of Finnish municipalities through in-person and online study visits and equipment-lending services (LUMA Centre Finland, 2026^[5]).

The model combines nationally supported infrastructure with regional and local provision. Its geographical reach indicates substantial delivery capacity, but does not by itself establish changes in teaching, subject choice or later entry into STEM higher education. Monitoring would need to examine the quality and continuity of participation, changes in classroom practice and subsequent educational outcomes across municipalities and learner groups.

The Estonian Engineering Academy extends this collaborative approach across general, vocational and higher education. Launched in 2023 and funded through 2029, it responds to declining interest in technical subjects, weaknesses in mathematics and science preparation, shortages of STEM teachers, attrition from engineering education and low participation among girls and women. It brings together government ministries and agencies, five higher education institutions, nine vocational providers, general schools, employers and professional associations.

Engineering days, factory visits and applied modules based on MATIK, Estonia's integrated approach combining mathematics, natural sciences, technology, engineering and the arts, are provided for Grades 7-12, alongside digital resources and targeted provision for girls. These activities are combined with curriculum modernisation, teacher development, jointly produced learning materials, laboratory investment and stronger routes from vocational to higher education. Intended outcomes include increased enrolment in priority engineering fields, reduced withdrawal from engineering education and greater female participation (Education and Youth Board, n.d.^[6]; Ministry of Education and Research, 2023^[7]; Ministry of Education and Research, 2024^[8]).

The Academy illustrates an effort to connect early experience and preparation with subsequent educational routes and the capacity of receiving institutions. Its scope may improve coherence, but also creates

substantial implementation demands. Responsibilities, resources and monitoring need to remain aligned across education sectors and participating organisations. Any increase in enrolment also needs to be matched by sufficient teaching, laboratory and learner-support capacity in vocational and higher education.

Taken together, these examples show that strengthening the foundations for STEM participation requires sustained investment in teacher expertise, curriculum, school leadership, laboratories and digital infrastructure, supported by collaboration among schools, teacher education, vocational providers, universities and other partners. OECD work emphasises the importance of teaching quality, supportive learning environments and equitable opportunities to learn (OECD, 2024^[9]). Monitoring should extend beyond activities and geographical coverage to examine changes in teaching and learning, access to relevant subjects, preparation, subject choice and subsequent entry across learner groups. This would help establish whether interventions address the unequal foundations for STEM participation discussed in Chapter 1.

2. Widening access to substantive STEM experiences

Practical STEM experiences can help learners explore fields, develop relevant knowledge and gain contact with higher education institutions and programmes and peer learners. They seek to respond to the unequal access to substantive STEM experiences discussed in Chapter 1, which can limit learners' understanding of STEM fields.

Actua in Canada illustrates a nationally co-ordinated and locally delivered approach. Established in 1993, it supports a network of more than 40 organisations based in universities and colleges and operates across more than 600 communities. Its rationale is that access to STEM experience differs according to geography, school resources and socio-economic circumstances, as well as representation in scientific and technical fields. It places particular emphasis on girls, First Nations, Inuit and Métis youth, Black youth, newcomers, learners with disabilities, learners facing socio-economic barriers and young people in rural, remote and northern communities (Actua, 2025^[10]).

Camps, clubs, classroom workshops and community activities are delivered on higher education campuses and in locations where learners already participate. Nationally developed resources and quality expectations provide a common structure, while member organisations adapt content, scheduling, language, mentors and learning environments to local circumstances. In Indigenous communities, activities may be developed with community partners and connect STEM learning with local environments and Indigenous knowledge.

Paid undergraduate instructors are an important part of the model. Approximately 1 000 postsecondary learners are employed each school year as instructors and near-peer role models. Their preparation covers pedagogy, communication, conflict resolution, accessibility, anti-racism, gender equity, Indigenous worldviews and community engagement. The arrangement can widen access for younger learners while enabling the undergraduate instructors to develop communication, leadership and professional competence (Actua, 2025^[11]; Romkey et al., 2023^[12]).

In 2024, Actua reported 604 808 youth engagements and 3.4 million hours of face-to-face provision. Among surveyed participants, 62% reported greater confidence in their STEM abilities, 45% reported greater interest in taking optional STEM subjects and 47% reported greater interest in studying STEM in higher education (Actua, 2025^[10]; Actua, 2025^[13]). These indicators show extensive reach and positive immediate outcomes among respondents. Longitudinal monitoring would be needed to establish whether participants subsequently select relevant subjects, develop the necessary preparation and apply to or enter STEM higher education.

The “*Informatik-Werkstatt*” (*Computer Science Workshop*) at the University of Klagenfurt provides a complementary facility-based model. It developed from a mobile school offer established in 2013 into a university summer format and subsequently a permanent weekly facility. It provides workshops for children,

school classes, families, teachers and students on algorithms, programming, robotics, encryption, networks, modelling and computer systems (Pasterk et al., 2016^[14]; RFDZ Informatik, n.d.^[15]).

Activities range from standalone workshops to thematic blocks delivered over several sessions. The initiative is intended to stimulate early interest, broaden perceptions of informatics beyond computer use and develop computational thinking. Evaluation using questionnaires, interviews, observations, knowledge checks and assessment of participant products found short-term improvements in interest and self-reported knowledge.

The initiative also shows how delivery formats can address geographical access. Earlier mobile workshops brought provision to schools, while the permanent university facility provides specialist expertise, equipment and continuity. An online repository enables teachers and teacher-education learners to use materials outside the immediate area. In 2025, the university reported plans to renew mobile provision for more distant schools, subject to financing (University of Klagenfurt, 2025^[16]).

In Poland, since 2007, the Perspektywy Education Foundation, in cooperation with the Conference of Rectors of Polish Technical Universities, has organised the nationwide programmes *Girls to Technical Universities!* and *Girls into Science!*. The initiatives aim to increase the participation of women in STEM fields by providing information on study opportunities, role models, mentoring activities and outreach campaigns targeting upper-secondary students. These activities are complemented by Perspektywy Women in Tech, which supports networking, mentoring and career development for women in technology and engineering, extending support beyond entry into STEM education. The campaigns are supported by annual evidence-based monitoring through the *Women at Technical Universities* report, prepared jointly with the Information Processing Centre – National Research Institute. The initiatives illustrate how long-term collaboration among higher education institutions, data providers and civil society organisations can contribute to broadening participation and challenging gender stereotypes in STEM education.

The examples combine specialist expertise with wider geographical and social access in different ways. Actua uses national co-ordination, local adaptation and paid near-peer instructors to bring provision into communities. *Informatik-Werkstatt* combines a permanent university facility with mobile, online and teacher-mediated provision. The Polish programmes combine nationwide outreach, mentoring and role models with long-term collaboration among higher education institutions and annual monitoring of women's participation in technical universities. All three approaches require continuing institutional support, trained educators, appropriate equipment and delivery arrangements adapted to participants' circumstances. Policymakers should assess whether these experiences are sufficiently substantive, sustained and accessible across participant groups, and use the findings to adapt their design and delivery.

3. Strengthening relevance and belonging

Learners are more likely to consider a STEM programme when they find its content and activities meaningful, believe they can develop the preparation needed to succeed and perceive that they “fit in”. The following examples seek to connect STEM with societal purposes enabling learners to participate actively rather than encounter STEM only through information or representation.

Ireland's STEM Passport for Inclusion combines STEM engagement, mentoring, contact with industry and a recognised educational award for girls attending disadvantaged secondary schools (Maynooth University, n.d.^[17]). Developed initially as a pilot and subsequently expanded, it provides a more sustained intervention than a single outreach event. Participants can obtain a certificate referenced to the Irish qualifications framework.

The initiative combines practical participation, role models, guidance, mentoring and contact with industry. Its policy relevance lies in connecting interest and confidence with learning and recognition rather than treating them as independent outcomes. Reported activity data indicate substantial participation and programme completion (Research Ireland, n.d.^[18]). Its contribution to wider entry will depend on whether

the recognised learning strengthens preparation or supports admission and whether participants subsequently make informed subject and programme choices.

Swiss TecLadies provides sustained mentoring for girls and young women 14 to 19 years old (SATW, 2024^[19]). Participants engage in workshops, visits and project activities and establish contact with women in technical professions. The programme seeks to make technical education and careers more visible, expand professional networks and provide support over several months.

The case illustrates how role-model interventions can move beyond brief exposure. Its principal mechanism lies in sustained interaction, practical information and access to a network rather than the demographic characteristics of mentors alone. Monitoring should examine the quality and continuity of mentoring, the information participants obtain about educational requirements and routes, and whether participation affects later choices.

The ADA initiative, or *Algorithms Think Differently*, combined practical computing with attention to gender stereotypes, societal applications and the responsible use of technology. Implemented by the Vienna Center for Logic and Algorithms at TU Wien from July 2019 to June 2022, it developed German-language computational-thinking resources, including practical activities not requiring computers. Its Hackathons for Good AI connected programming and artificial intelligence with challenges such as climate change, health and misinformation (VCLA, n.d.^[20]). Participants investigated a problem, used information sources, developed chatbot dialogues in Scratch and considered how technology might contribute to the public good. The intended outcomes included computational understanding, confidence in engaging with digital technologies and a broader understanding of computing as a socially relevant field.

The related “Diary of a Female Computer Scientist” brought women researchers and computing professionals into Austrian secondary schools. Workshops enabled girls to discuss education, research and professional work, question stereotypes and reflect on their own capabilities and aspirations. Strong demand from schools also demonstrated the organisational importance of recruiting, preparing and co-ordinating suitable mentors (VCLA, n.d.^[20]; TU Wien, 2020^[21]).

Australia’s Diversity in STEM toolkit provides curriculum-aligned resources for primary- and secondary-school learners, teachers, families and carers (Education Services Australia, 2025^[22]). It seeks to help learners explore STEM opportunities and envisage themselves in STEM education and careers, with particular attention to groups under-represented in STEM occupations. The related Australian Superstars initiative, operating since 2017, promotes the public and media visibility of people from different backgrounds working in science, technology, innovation and industry (Women in AI Australia, n.d.^[23]).

These measures use information and representation rather than sustained practical participation as their principal mechanism. They may broaden awareness and challenge stereotypes, but their effects depend on whether schools and families use the resources and whether greater visibility is connected with subject access, preparation, guidance and attainable educational routes. Representation can support perceived belonging but cannot substitute for opportunities to acquire the relevant competence.

Bringing arts and natural sciences together in arts-science collaboration provides another way to connect STEM with learners’ interests, experiences and societal concerns. “Cultural Collisions” and the “Circus of Knowledge” use sustained creative activity to make scientific and technological questions accessible and personally meaningful. Their relevance here lies in learner engagement and perceived relevance (see Policy Priority 3 for integrating STEM and non-STEM disciplines).

“Cultural Collisions” connects technical and arts universities, teacher-education institutions, schools, museums and cultural organisations. A recent implementation at the Technical University of Vienna ran for four annual cycles, from 2022/23 to 2025/26, and addressed cities and buildings, energy, mobility and the circular economy (TU Wien, n.d.^[24]). These topics can strengthen relevance by connecting scientific and technological questions with learners’ surroundings, experiences and societal concerns. Combining STEM with artistic and creative work can also broaden the ways in which pupils participate and see a place

for themselves in STEM. Each cycle combined interdisciplinary university courses, an initial exhibition for pupils, school-based creative work, museum workshops and a concluding public exhibition. Pupils, mainly aged 12 to 14, developed artistic responses to scientific and technological questions with support from teachers, university learners, researchers, artists and museum educators. Related participatory research involving pupils and teachers identified improvements in helpfulness and reduced discrimination within classroom relationships.

The “Circus of Knowledge” at Johannes Kepler University Linz combines a permanent interdisciplinary performance venue with school and public activities using theatre, film, movement, music, radio and other artistic methods. Its publicly funded Sparkling Science intervention, implemented between 2022 and 2025, embedded artist-led workshops in regular lessons, generally twice weekly for seven weeks. Activities addressed topics including the circular economy, forest ecosystems and atomic bonding, while funding covered school participation, travel, excursions and performance tickets (JKU, n.d.^[25]).

These examples show that relevance, confidence and belonging are more likely to be strengthened when positive representations are connected with sustained relationships, practical participation and viable educational or occupational routes. Short-term outreach should form part of a broader institutionally anchored approach addressing preparation, access, programme culture and progression. Monitoring should extend beyond attendance and self-reported confidence to subject choice, preparation, entry, persistence and differences in outcomes across learner groups. This can help determine whether interventions affect the participation patterns identified in Chapter 1 rather than only learners’ immediate perceptions.

4. Supporting informed choice and transition into higher education

Prospective learners need accurate and comparable information, opportunities to test their expectations and guidance that continues across application, enrolment and initial study. Information services, direct experience, guidance and sustained mentoring perform complementary functions. As the following examples illustrate, their purpose should be to support informed and viable choices rather than direct every participant towards STEM higher education.

Studienplattform.at, operated by the Austrian Students’ Union, provides information on programme location and content, fees, admission restrictions, entrance procedures, guidance services and student representatives. It also identifies routes for learners without a conventional school-leaving certificate, including subject-specific entrance examinations, vocational matriculation and qualification routes for universities of applied sciences. It serves recent school-leavers as well as vocational learners, adults and internationally educated applicants (ÖH, n.d.^[26]).

“Studieren Probieren” (Try Out University Life) complements this information by allowing prospective learners to attend a lecture or online session accompanied by a current student and then discuss the programme, academic expectations and student experience. In the 2024/25 academic year, it offered approximately 1 276 appointments, with 9 851 places and 9 795 registrations across more than 50 institutions and over 300 study areas per semester (ÖH, n.d.^[27]).

The two services show how standardised information and direct experience can be combined. The platform enables learners to compare formal requirements and routes, while participation in a class and discussion with a current learner can make programme content and expectations more concrete. Registration figures indicate substantial use, but do not establish whether participants understand their options better, choose more suitable programmes or experience stronger early persistence. These outcomes would require follow-up across application, enrolment and initial study.

BeFirst! at the University of Klagenfurt uses university-student mentors to advise pupils during their final year of school and support first-generation learners during the initial stage of higher education. Its free provision covers programme choice, enrolment, finance and scholarships, housing, timetabling,

examination registration and academic learning practices. Mentoring is complemented by workshops, networking, writing support and a first-year course worth four ECTS credits. The programme reports that approximately one-third of participating secondary-school learners subsequently enter the University of Klagenfurt (Vitouch, 2024^[28]).

The intervention extends across the boundary between school and higher education. This continuity may be particularly important for first-generation learners because procedural and academic questions continue after admission. The reported transition rate describes an outcome among participants but does not establish how many would otherwise have entered the university or whether the route selected was the most suitable one.

“*Studienkompass*” (Study Compass) has operated in Germany since 2007 and provides a structured three-year offer covering the final two years of school and the first year of higher education or vocational training. It combines workshops, coaching, regional activities, digital resources and support from trained volunteer mentors. Participants explore education and training options, finance, personal strengths, confidence, digital competence and career planning (Studienkompass, 2026^[29]). Its duration allows guidance to respond as learners’ plans develop and as they encounter application and transition requirements.

Together, these examples show that informed choice can be strengthened by connecting comparable information with direct experience and sustained guidance. Public authorities can support common and accessible information, while schools, higher education institutions, student organisations and guidance services provide different forms of interpretation and transition support. Monitoring would need to examine learners’ understanding of study programmes and requirements, their movement into suitable routes and their initial progress, rather than participation in guidance alone. It should also assess whether provision reduces unequal access to information and guidance, identified as bottleneck contributor in Chapter 1.

5. Using diagnostic assessment to identify and address preparation needs

Diagnostic assessment can make programme expectations visible and identify specific preparation needs. Effectiveness depends on whether learners receive feedback they can understand and whether accessible opportunities are available to address the needs identified. As the examples show, diagnostic assessment intended to support preparation should not operate as an additional or informal admission barrier.

Italy’s Scientific Degree Plan, “*Piano Lauree Scientifiche*”, combines self-assessment, laboratory learning and academic preparation across the transition into STEM higher education (Pressi, 2016^[30]). The initiative has evolved from an initial emphasis on increasing enrolment towards a broader concern with preparation, early progression and completion.

Self-assessment can make preparation needs visible, while knowledge-recovery activities and tutoring provide an educational response. Laboratory learning enables learners to connect scientific concepts with evidence and practical enquiry. Structured collaboration between secondary schools and higher education institutions can improve continuity between school preparation and early university study by connecting assessment, preparatory activities and the requirements of receiving programmes.

Activities in natural sciences, physics and chemistry illustrate how secondary learners can assess their scientific competence, participate in practical or computational laboratory work and consolidate knowledge required for entry into scientific degree programmes. Co-design by secondary-school teachers and university academics can strengthen the relationship between the assessment, the preparation provided and the requirements of receiving programmes. Embedding this collaboration in institutional agreements, co-ordination arrangements and recognised staff responsibilities can make it less dependent on individual educators and more sustainable over time.

Flanders' calibration and start tests provide a programme-specific means of identifying differences between prospective learners' competence and the requirements of STEM bachelor's programmes (Fonteyne et al., 2026^[31]). First introduced across Flemish universities in 2013 for science and engineering, the tests assess mathematics, scientific problem-solving, academic reasoning and other programme-relevant knowledge and capabilities.

Participation has become compulsory for a growing number of STEM programmes, while results remain non-binding for admission. The tests are intended to make expectations transparent and give learners an early indication of their preparation. Evidence from Flemish science and engineering programmes shows that results are associated with first-year achievement and can identify learners at elevated risk of academic difficulty (Fonteyne et al., 2026^[31]).

Inter-university evidence also indicates that the calibration and start tests provide information beyond secondary-school results and teacher recommendations. Learners with lower scores are more likely to reconsider or change their intended programme, particularly where they were already uncertain (Pinxten et al., 2017^[32]). This may support more informed choice, but it may also discourage learners who could succeed with suitable preparation.

Together these examples demonstrate that diagnostic assessment should be part of an educational response. Assessment can clarify expectations, but institutions and public authorities need to ensure that suitable preparation, tutoring or bridge provision is available and practically accessible. Monitoring should examine who participates, how learners interpret and act on the results, whether support reaches those who need it, and whether learners subsequently enter and progress in suitable programmes. It should also identify whether assessment and support reduce differences in preparation or reproduce the gaps discussed in Chapter 1.

Lessons across the approaches

The examples show that preparing and guiding learners towards STEM higher education requires more than encouragement and information. Effective routes combine strong educational foundations, substantive STEM experiences, a sense of relevance and belonging, informed choice, clear entry requirements, accessible preparation and support during the transition into higher education.

The five approaches address different but connected constraints. Strong teaching, suitable curricula and learning environments help learners develop the preparation required for STEM higher education. Substantive experiences allow them to explore fields and take part in scientific and technical activity. Mentoring, role models and engagement with societal problems can strengthen relevance and belonging. Information, direct experience and sustained guidance support informed choices. Diagnostic assessment can identify preparation needs when it leads to accessible tutoring, bridge provision or other support. Together, these approaches respond to the connected constraints identified in Chapter 1, including unequal preparation, access to relevant subjects and experiences, information and guidance, perceived relevance and belonging, and the financial and practical accessibility of educational routes.

These approaches therefore need to be connected around the constraints affecting particular learners and routes. Practical experience and role models may strengthen interest and broaden perceived possibilities, but cannot remove academic, financial or geographical barriers. Information and diagnostic assessment may clarify requirements and preparation needs, but their contribution depends on whether learners can access the subjects, preparation and support needed to act on them.

Public policy's role is to support co-ordination across school, vocational and higher education; address geographical and social differences in access; finance provision with wider public benefits; and establish expectations for information, recognition and monitoring. Schools, vocational providers and higher education institutions remain responsible for teaching, guidance, assessment and preparatory provision. Where preparation and transition span education sectors, structured institutional collaboration can connect

curriculum expectations, diagnostic assessment, preparatory learning and learner support. Agreements, designated responsibilities and recognised staff time can make this collaboration more consistent and sustainable than arrangements dependent on individual educators. Employers, professional bodies, museums and civil-society organisations can contribute practical experience, occupational information, mentors and access to scientific and technical communities.

The approaches show that policy monitoring needs to identify who participates, who benefits and who remains excluded. Longer-term evidence on subject choice, preparation, application, entry and early progress can show whether interventions address the bottlenecks identified in Chapter 1, widen access and support suitable choices, or mainly benefit learners who already have strong preparation and familiarity with higher education.

Effective action requires sustained capacity. Teacher development, laboratories, outreach, mentoring, guidance, diagnostic assessment and transition support depend on qualified staff, suitable infrastructure, co-ordination and continuing finance. Short-term or disconnected initiatives may reach many learners without changing the underlying conditions that shape preparation, eligibility and entry. Increased entry also needs to be matched by sufficient teaching, infrastructure and learner support in receiving institutions.

1.2 Strengthen teaching, assessment, belonging and programme coherence to support persistence and completion

Policy rationale, intended outcomes and risks

STEM programmes often build progressively on earlier learning. Difficulty in an introductory or prerequisite course can restrict access to subsequent courses, delay progression and increase the duration and cost of study. Such difficulties may reflect gaps in preparation, but may also arise from course design, teaching, assessment, workload, unclear expectations or insufficient opportunities to practise and receive feedback. This distinction is important because the evidence reviewed in Chapter 1 cannot establish from completion data alone whether the principal constraint lies in learners' prior preparation or in programme conditions.

Gateway courses should maintain the disciplinary and methodological foundations required for later study while giving learners realistic opportunities to develop them. Early and formative assessment, opportunities to practise and timely, actionable feedback can identify learning needs before a high-stakes examination determines progression. Post-enrolment diagnostic assessment should guide teaching and support rather than reopen admission decisions or classify learners generally as being at risk. Additional teaching should be aligned with the courses in which the knowledge is required and should not impose excessive workloads or separate learners unnecessarily from the mainstream programme.

Active, inquiry-oriented and application-based teaching can help learners connect disciplinary foundations with professional and societal applications. Projects, laboratories, modelling, design and authentic problems can strengthen learning and participation. However, collaborative activity does not guarantee equitable access to substantive work. Learners with greater confidence, previous technical experience or social status may dominate equipment use, programming, analysis and decision making, while others undertake mainly administrative or presentational tasks. Programme design and assessment should therefore make individual learning and participation visible and give all learners opportunities to develop and demonstrate disciplinary, interdisciplinary, transversal and professional competence.

Belonging is part of programme quality. It concerns whether learners feel accepted, respected, supported and recognised as legitimate participants in a programme and its field. Teaching, feedback, classroom climate, relationships with educators and peers, and access to technical and leadership responsibilities all shape this experience. Targeted mentoring or networking may be valuable, but cannot compensate for exclusionary teaching, inaccessible curricula or discrimination in the mainstream programme. This

responds to the differences in participation and progression discussed in Chapter 1, which formal access and aggregate completion indicators cannot explain on their own.

Student support, including academic, personal and psychosocial support, can help learners understand expectations, address learning and practical difficulties, and respond to challenges affecting well-being, adjustment, relationships and belonging. These forms of support should be accessible and connected with programme requirements, but will have limited effects unless courses, prerequisites, assessment, practical learning, schedules and services are co-ordinated through sufficiently resourced programme leadership.

Institutional evidence should help identify recurring barriers, determine their causes, assign responsibility, implement changes and evaluate their effects. Institutions should combine evidence on performance, credit accumulation, repetition, transfer, interruption and completion with information on workload, learner experience and programme conditions. Transfer may represent a constructive change of route rather than failure to persist, while increased use of support may indicate greater need or improved accessibility and trust. Predictive and early-warning systems may enable timely support, but can reproduce historical inequalities, label learners or direct attention towards individual risk rather than programme conditions. Their use should therefore be transparent and proportionate, connected with accessible support and evaluated for effects on learning, equity, stigma and trust.

Public policy has a role where institutions lack the resources, expertise, evidence or incentives needed to address recurring barriers; where increased entry is not matched by teaching and support capacity; or where programme conditions contribute to avoidable differences in persistence and completion. Public authorities can support institutional capacity, establish expectations for programme quality and evidence use, and ensure that funding recognises the resources required for effective teaching, assessment, practical learning and learner support. Higher education institutions remain responsible for programme design, teaching, assessment, learner support and qualification standards.

The intended outcomes are stronger learning, timely progression, greater belonging, completion with the intended competence and fewer avoidable differences in outcomes among learner groups. Consistent with the limitations of completion indicators discussed in Chapter 1, monitoring should distinguish withdrawal from transfer, interruption, continued enrolment, delayed completion and completion elsewhere. It should also examine whether learners develop and demonstrate the intended disciplinary, interdisciplinary, transversal and professional competence.

The principal risk of policy interventions to strengthen persistence and completion is that they add demands on learners and staff without addressing weaknesses in mainstream programmes. Additional assessment and support may overwhelm learners or separate them from programme communities; collaborative learning may reproduce unequal participation; and early-warning systems may label learners without leading to timely support. Policy should therefore connect evidence, programme leadership, teaching development and learner support. Where recurring patterns indicate structural barriers, responses should improve mainstream curriculum, teaching, assessment and programme organisation rather than rely principally on learners to adapt or seek additional assistance.

Examples of interventions

The examples illustrate two connected approaches to supporting persistence and completion: diagnosing barriers and connecting evidence with co-ordinated academic and psychosocial support; and using diagnosis to redesign the curriculum, assessment and organisation of the first-year engineering experience.

The approaches operate at different levels. Institution-wide structures can identify common patterns, provide specialist expertise and co-ordinate support. Faculty- and programme-level arrangements can respond to discipline-specific learning requirements and redesign the courses and transitions in which difficulties occur.

Table 2.3. Selected interventions to support persistence and completion in STEM programmes

Approach	Example	Principal policy contribution
1. Connecting diagnosis with co-ordinated support and institutional improvement	Student Trajectory Observatory and Tutoring Programme, University of Aveiro, Portugal; Strategic Education Development Centre, TU Wien, Austria; Student Support Centre, Faculty of Informatics, Eötvös Loránd University, Hungary; <i>InES Género</i> , Chile	Connect evidence on progression, workload and learner experience with teaching development, mentoring, counselling, inclusive institutional practices and programme review.
2. Using diagnosis to redesign the first-year engineering experience	Student Success Model, Technological University of the Shannon, Ireland; common-entry engineering at the University of Limerick, Dublin City University and Technological University Dublin, Ireland; Technology Education of the Future, NTNU, Norway	Redesign foundational learning, assessment, specialisation and participation in engineering practice in response to evidence on non-progression, programme fit and curriculum coherence.

1. Connecting diagnosis with co-ordinated support and institutional improvement

Evidence on progression, assessment, workload, learner experience and use of support services can help institutions identify where and why learners encounter recurring difficulties. As discussed in Chapter 1, aggregate indicators cannot show whether delayed progression or non-completion arises from learners' preparation and circumstances, particular courses and transitions, or wider programme conditions. Diagnosis contributes to persistence and completion only when it leads to changes in teaching or programme organisation and to accessible academic, practical and psychosocial support. This evidence can help institutions distinguish difficulties associated with preparation or adjustment from barriers arising through teaching, assessment, curriculum sequencing, programme workload or access to support. Patterns concentrated in particular courses, prerequisites or transitions may indicate a need to change mainstream provision rather than classify individual learners as being at risk.

Co-ordinated institutional structures can connect this evidence with expertise in teaching, curriculum, mentoring and learner support. Academic support includes tutoring, learning guidance and assistance with course requirements; practical support includes help with financial, administrative, accessibility and student-life matters; and psychosocial support includes counselling and other specialised provision. Some services and structures operate across an institution and can identify patterns extending beyond individual courses or programmes. Others are located within faculties and respond more directly to the requirements of particular disciplines.

The University of Aveiro combines monitoring of learner trajectories with tutoring, mentoring, academic guidance, course review and professional development for educators. Its developing Student Trajectory Observatory, known as OPE, monitors educational routes and identifies patterns associated with delayed progression and withdrawal. It complements the university's quality-assurance arrangements and Institutional Indicators Portal (University of Aveiro, n.d.^[33]). Evidence is drawn from academic records, pedagogical surveys and course reports and covers progression, transfer, delayed completion, withdrawal, grades and selected learner characteristics. Combining these sources can help the university examine whether difficulties are concentrated in particular courses, transitions or learner groups and whether they reflect preparation, teaching, assessment or programme organisation.

The university's Tutoring Programme connects this institutional evidence with support during the transition into higher education. The programme pairs new learners with experienced student mentors supported by academic tutors. In the 2025/26 academic year, it involved more than 900 mentors, 140 tutors and 1 400 learners across 44 programmes. Preparation for mentors and tutors addresses the transition into higher education, mental health, emotional support, discrimination and empathetic communication (University of Aveiro, 2026^[34]). The scale of participation demonstrates substantial institutional provision, but does not establish its effects on learning, persistence or completion. Evaluation could connect participation in tutoring with subsequent credit accumulation, continuation and completion, while accounting for differences in learners' circumstances and reasons for participating. Programme-level

analysis is also needed to determine whether the patterns identified in Chapter 1 reflect difficulties requiring changes to teaching, assessment or curriculum rather than additional learner support alone.

TU Wien's Strategic Education Development Centre provides a central structure for educational development and teaching quality. Located within the Vice Rectorate for Academic Affairs, it brings together quality management, didactics, study-related data analysis and workload monitoring and connects university leadership, academic staff and learners (TU Wien, n.d.^[35]). This combination allows barriers extending beyond individual courses to be examined and connects evidence with faculties, programme leaders and institutional decision-making.

Since 2019, TU Wien has monitored learners' study effort through an anonymous diary-style mobile application. Reported workload is compared with planned ECTS allocations, providing evidence on actual study effort and its distribution across courses and programmes. Findings are prepared for study commissions, deans of studies and teaching-quality processes and can inform decisions on credit allocation, assessment, scheduling and curriculum design (TU Wien, n.d.^[36]). This approach can reveal programme-level problems that are difficult to identify when courses are considered separately. Several courses may each appear manageable while their combined deadlines, assessment requirements and prerequisites create excessive or uneven workloads.

Workload evidence does not, however, produce improvement on its own. Its contribution depends on whether participation is sufficiently representative, whether the findings are interpreted in relation to course and programme requirements, and whether responsible bodies have the authority and resources to revise curriculum, scheduling and assessment. Monitoring could examine whether changes introduced in response improve workload distribution, credit accumulation and timely progression. This provides one way to investigate programme conditions that aggregate progression and completion indicators discussed in Chapter 1 cannot reveal. Institutional leaders and public authorities can support this work by recognising the staff time, analytical expertise and programme leadership required to translate evidence into educational change.

Institution-wide arrangements can identify common barriers, while provision embedded within a faculty can respond to discipline-specific demands. The Student Support Centre at the Faculty of Informatics of Eötvös Loránd University in Hungary, known by its Hungarian abbreviation DTK, or *Diáktanácsadó Központ* (Student Counseling Center), combines learning-methodology courses, faculty and senior-student mentoring, psychological counselling, community activities and research on learner progression. Its multidisciplinary team includes psychologists, counselling psychologists, lecturers and researchers familiar with the academic and social demands of computing education (Takács et al., 2022^[37]).

Support is organised around significant transitions, including entry into the first year and preparation for master's study. First-year participants are connected with a faculty mentor, a senior student and a psychological trainer. Activities address course expectations, university procedures, study methods, time management, stress, communication and collaborative work. English-language and interculturally informed mentoring extend provision to international learners. Academic support is complemented by personal support, including free psychological counselling and connections with university-wide, disability-related and student services or external specialist provision where required.

A study of nearly 4 000 first-year learners informed a wider reform combining compulsory attendance with universal prevention and study-skills provision. Following the combined reform, more learners remained engaged through the first two semesters and attempted examinations, and the university reported a 28% reduction in dropout over two years (Takács et al., 2022^[37]). The reported outcome is consistent with an improvement in persistence, but the reform combined several measures and does not establish their separate effects. Continued monitoring could examine whether the change is sustained, whether it is accompanied by stronger learning and credit accumulation, and how outcomes differ by course and learner group. The example nevertheless shows the value of locating academic and psychosocial support close to the programme while maintaining connections with specialist institutional services.

Chile's *InES Género* programme, or Innovation in Higher Education for Gender Equality, shows how public funding can support the organisational capacity required for more inclusive educational and research environments. It responds to the differences in participation and progression across learner groups discussed in Chapter 1 by addressing institutional conditions that may influence belonging, access to opportunities and continued participation. It provides higher education institutions with up to CLP 450 million over 36 months to develop institutional capacity for gender equality (ANID, 2025^[38]). Its contribution lies less in a single learner-facing activity than in financing the structures, expertise and institutional change needed to embed inclusive teaching, mentoring, progression and research practices. Multi-year funding can allow institutions to establish responsibilities, develop expertise and create co-ordination arrangements that would be difficult to sustain through short-term interventions.

Funding and completed activities provide evidence of implementation, but do not establish whether learners experience more inclusive teaching, greater belonging or more equitable progression. Monitoring should examine changes in programme practices, experiences of belonging and discrimination, access to mentoring and research opportunities, and progression and completion across learner groups. Sustainability is also important. The programme's longer-term contribution depends on whether participating institutions incorporate effective responsibilities, staff and practices into mainstream governance and financing after the dedicated funding period. Public funding can support this by requiring credible plans for institutionalisation while allowing approaches to be revised where monitoring does not indicate the intended changes.

Together, these examples illustrate complementary ways of connecting diagnosis with action. Aveiro brings together evidence on learner trajectories and structured mentoring. TU Wien connects workload monitoring with educational development and institutional decision-making. Eötvös Loránd University locates connected academic and personal support within a discipline-specific faculty. *InES Género* uses public funding to develop organisational capacity for more inclusive institutional practices.

These arrangements can help institutions investigate the differences in progression and completion identified in Chapter 1, which aggregate indicators cannot explain. Evidence should not be used principally to identify individual learners considered at risk. It should also reveal whether teaching, assessment, workload, curriculum or programme organisation creates recurring barriers. Effective institutional arrangements require clear responsibilities, trained and supervised mentors, qualified academic and personal support staff, educational development expertise and decision makers with sufficient authority and resources to act. Monitoring should examine not only whether support is provided, but also whether evidence leads to changes in mainstream provision and whether these changes improve learning, progression, belonging and completion across learner groups.

2. Using diagnosis to redesign the first-year engineering experience

Diagnosis may indicate that recurring difficulties cannot be addressed through additional learner support alone. Changes to mainstream curriculum, teaching, assessment and programme organisation may be required. This distinction is important in light of Chapter 1, which shows that relatively high entry into core STEM may not necessarily coincide with relatively high completion and that aggregate data cannot identify the programme conditions underlying this pattern. First-year engineering provides a relevant illustration because foundational learning, programme fit, specialisation, practical participation and early assessment can be addressed together.

Broad-entry structures can provide shared foundations, postpone specialisation and give learners experience of different engineering fields before they select a route. Co-ordinated courses can make the relationships among mathematics, science, computing and engineering more visible, while early projects, laboratory activities, regular assessment and feedback can connect theoretical learning with engineering practice and identify difficulties before final examinations determine progression.

The Student Success Model at the Technological University of the Shannon was developed in response to high non-progression. It combines a redesigned first-year curriculum and assessment with transition assistance and co-ordinated academic and learner support (Ross and McNamara, 2025^[39]). The model is based on institutional commitment to persistence and completion, clearly allocated responsibilities within a collaborative faculty team, and progressive support towards learner independence.

Following a programme review in 2015, the curriculum was revised, a compulsory “Learning and Development for Higher Education” module was introduced, and assessment was mapped to graduate attributes and distributed more regularly across the year. Induction, peer mentoring, targeted tuition, meetings following module failure, field visits and contributions from employers and graduates connect academic support with programme understanding, professional relevance and belonging. The intervention illustrates how curriculum, assessment and support can be treated as connected components rather than separate activities.

Because several changes were introduced together, their individual effects cannot readily be isolated. Monitoring across successive cohorts could examine foundational-course performance, assessment completion, credit accumulation, continuation and completion. Analysis across learner groups could show whether the redesigned experience reduces the differences associated with prior preparation and circumstances discussed in Chapter 1.

Common-entry engineering programmes at the University of Limerick, Dublin City University and Technological University Dublin use broad disciplinary entry and delayed specialisation to support the first-year transition. Their purpose is to develop shared foundations, give learners experience of different engineering fields and support a more informed choice of specialisation.

The University of Limerick provides a common first year before learners select an engineering discipline (University of Limerick, n.d.^[40]). Dublin City University develops shared foundations in engineering mathematics, materials, basic sciences, electronics, software development, technical drawing and professional development before learners enter a specialised programme in the second year (Dublin City University, n.d.^[41]). Technological University Dublin similarly combines mathematics, physics and chemistry with mechanics, electrotechnology, technical graphics, computing and professional development. Laboratory activities and design projects in areas including robotics, bridge design and energy efficiency connect theoretical learning with engineering practice from the beginning of the programme (Technological University Dublin, n.d.^[42]).

These structures may help learners understand different engineering fields, establish common foundations and make a more informed choice of specialisation. Their effects cannot be inferred from programme design alone. Monitoring should examine learners’ initial preferences, subsequent specialisation choices, movement between routes, academic performance, persistence and completion. This would help establish whether common entry improves progression and programme fit or merely relocates selection and attrition to the point of specialisation.

If access to preferred fields depends on grades or limited places, common entry may postpone rather than remove a competitive selection point. Institutions should therefore be transparent about allocation rules and provide suitable guidance across the available routes. An example is NTNU’s Technology Education of the Future initiative in Norway, which situates first-year reform within a broader process of programme renewal. Covering approximately 150 bachelor’s, master’s and doctoral programmes across five faculties, the process used international benchmarking, stakeholder consultation, institutional data, pilot experience and a SWOT analysis to develop a common vision, competence profiles and an implementation roadmap (Øien and Bodsberg, 2022^[43]).

The roadmap calls for common and programme-specific courses to be reviewed against intended graduate competence; stronger connections between mathematics, statistics and engineering applications; early team- and project-based learning addressing authentic problems; greater teaching capacity in the initial

years; and more regular assessment, feedback and interaction between learners and educators. Programme leaders are expected to map learning outcomes across courses, identify gaps and align content, teaching and assessment.

This work is supported by clearer mandates, educational-development expertise, information systems and dedicated resources. Responsibilities are distributed across institutional leadership, faculties, departments, programme leaders and course co-ordinators and incorporated into regular quality-assurance processes. The initiative therefore illustrates the organisational arrangements required to renew programmes across a large and diverse institutional portfolio.

A shared vision, competence profiles and implementation arrangements demonstrate a substantial programme-renewal process, but do not establish improvements in learning, persistence or completion. Monitoring across cohorts and implementation phases could examine changes in curriculum coherence, workload, feedback, substantive engineering participation, credit accumulation and completion. Comparison across programmes could help identify the institutional and programme conditions underlying the different completion patterns discussed in Chapter 1.

Public policy can support this form of longer-term change by providing institutions with sufficient time and resources to implement and evaluate programme reform. Short funding periods or expectations of immediate effects may encourage visible activities without allowing new teaching, assessment and organisational practices to become established.

Taken together, these examples illustrate three related forms of programme redesign. The Student Success Model connects curriculum, assessment and support in response to non-progression. Common-entry engineering combines shared foundations with delayed specialisation. NTNU embeds first-year change within a broader renewal of programmes and competence profiles. All three respond to the central diagnostic problem identified in Chapter 1: observed non-completion does not show whether difficulties arise from prior preparation, programme fit, particular courses and transitions, or the organisation of teaching and assessment. Their common contribution lies in shifting attention from individual difficulty to the programme conditions.

Lessons across the approaches

Improving persistence and completion means removing avoidable barriers and providing the teaching, feedback, substantive participation and support learners need to meet clear requirements. It should not mean lowering academic standards. Achieving this outcome requires institutions to turn evidence into educational and organisational action. Institution-wide arrangements can identify common barriers, co-ordinate academic, personal and psychosocial support and provide specialist expertise. Faculty- and programme-level arrangements can respond to discipline-specific requirements by improving courses, assessment and key transitions.

As Chapter 1 shows, aggregate indicators can identify differences in progression and completion but cannot explain their causes. Evidence on learner trajectories, workload and experience can help institutions determine whether difficulties are associated with preparation and personal circumstances, particular courses or transitions, or wider programme conditions.

Data require careful interpretation. Increased use of support may reflect greater need or improved accessibility and trust. Transfer or interruption may represent a constructive change of route. Early-warning systems may enable timely assistance but can also label learners or reproduce inequalities. Making effective use of data requires sustained investment in information systems, analytical expertise, programme leadership and staff time. Institutions also need clear responsibilities, authority and resources to act on the findings. Evidence should be used to support learners and improve programmes rather than penalise individuals.

Programme redesign can strengthen foundational learning, connect theory with practice, improve assessment and feedback, and support informed specialisation. It can also create new barriers if workload, allocation rules or access to laboratories and substantive project roles are not considered. Additional learner support cannot compensate for recurring problems in mainstream teaching, assessment, curriculum sequencing or programme organisation.

Belonging is an essential part of programme quality. Teaching, feedback, relationships and access to substantive technical and leadership responsibilities influence whether learners participate, seek assistance and continue after difficulty. Mentoring and inclusion initiatives can contribute, but their effects will remain limited if mainstream programmes reproduce exclusion or unequal participation.

Programme leaders need recognised time, authority, evidence and educational-development support to co-ordinate courses, prerequisites, assessment, practical learning and learner services. Reform also requires sufficient academic and technical staff, suitable infrastructure, manageable workloads and sustained funding. Public authorities can support these conditions and establish expectations for programme quality, inclusion, monitoring and responsible data use, while higher education institutions remain responsible for curricula, teaching, assessment, learner support and qualification standards.

1.3 Support financial feasibility, flexible continuation, transfer, interruption, re-entry and completion

Policy rationale, intended outcomes and risks

Financial and practical constraints can prevent learners from completing demanding STEM programmes. Tuition, housing, transport, equipment, care costs and forgone earnings may lead learners to work alongside study, reduce their study intensity, interrupt, transfer, leave or forgo STEM study altogether. Extensive paid work may reduce the time available for study, practical learning and support, while laboratories, fieldwork and group projects can be particularly difficult to combine with employment or care. Academic delay can then extend the duration and cost of study, creating further financial pressure. These circumstances may reflect financial need, caring responsibilities, health, disability or changing objectives.

Housing costs can be a particular barrier where specialised STEM programmes and research infrastructure are geographically concentrated. Substantial in-person participation may require learners to relocate, making formally available programmes inaccessible to those unable to afford suitable housing. The first European Affordable Housing Plan recognises that housing costs can prevent young people from entering or completing education and participating in mobility. Its proposed measures include investment in student housing, possible guarantees to reduce security-deposit requirements, support for innovative accommodation models and an Erasmus+ pilot for mobile students from disadvantaged backgrounds. The Plan also encourages support through the European Social Fund Plus and national schemes for affordable rental and shared housing (European Commission, 2025^[44]).

Different forms of financial assistance address different costs (see Chapter 1). Tuition support reduces fees, while maintenance grants, equipment and childcare assistance, emergency funding and paid study time can address living and participation costs or forgone earnings. Assistance needs to be sufficient, predictable and accessible in practice. Complex applications, attainment-based awards and strict continuation conditions may disadvantage learners with limited time or familiarity with administrative procedures or remove support after a temporary setback.

Employment can provide income, professional experience and opportunities to apply learning, but its effects depend on its demands and relevance to the programme. Related employment may strengthen learning and support career entry, while intensive, unpredictable or unrelated work may compete with study. Employer-linked arrangements can help manage this tension by combining experience at work with

academic learning within a co-ordinated structure. Flexible study arrangements can further help learners combine education with employment, care and other responsibilities.

Learners may adjust their study intensity or use part-time or hybrid provision, but formal flexibility does not necessarily provide a usable route. They still need access to required courses, laboratories, fieldwork, projects, mentoring and academic support. Provision may remain inaccessible if required activities occur only during working hours or course sequences assume full-time participation.

Where continuous participation is not possible, interruption and transfer can form part of a viable route to completion rather than indicate failure. Learners who interrupt need clear information about their academic and financial status, preserved credit and return procedures. Before re-entry, a designated contact can help determine whether previous learning remains current, identify any refresher or bridge provision required and establish a realistic completion plan. Learners who transfer similarly need clear information about recognised credit, remaining requirements and the effects on the cost and duration of study. Preserving credit supports return only when learners also have clear procedures, suitable preparation and a realistic route to completion.

Public policy has a role where financial constraints prevent participation in education with wider public benefits or fragmented support makes continuation difficult. Public authorities can provide financial assistance, support flexible routes and establish expectations for transfer and credit recognition. Higher education institutions remain responsible for programme organisation, academic standards, recognition decisions and access to substantive learning. The intended outcomes are equitable participation and viable routes to completion. Learners should be able to combine study with employment, adjust their study intensity, transfer, interrupt and return without unnecessary loss of previous learning. Financial assistance and flexible arrangements should reduce avoidable withdrawal while preserving academic standards, substantive learning and opportunities for further progression.

The principal potential risk is that support and flexibility are formally available but insufficient or difficult to use. Financial assistance may not cover relevant costs or may be withdrawn after a setback. Part-time, hybrid and employer-linked routes may create excessive workloads or restrict access to laboratories, projects and programme communities. Transfer and re-entry arrangements may require unnecessary repetition or leave essential learning gaps unresolved. Monitoring should therefore examine whether learners can use these arrangements to continue and complete their studies. It should distinguish among continued enrolment, transfer, interruption, re-entry, delayed completion and permanent withdrawal.

Examples of interventions

Effective policy connects financial assistance, programme organisation, guidance, academic support, transfer, interruption and re-entry. The examples illustrate two connected approaches: treating employment, interruption and re-entry as possible integral parts of an educational route; and supporting financial feasibility through targeted assistance.

Table 2.4. Selected interventions to strengthen retention and belonging in STEM programmes

Approach	Example	Principal policy contribution
1. Treating employment, interruption and re-entry as part of the educational route	Study & Work programme, Johannes Kepler University Linz, Austria; dual study programmes, Germany; research and redesigned interruption and re-entry arrangements, University College London, United Kingdom	Co-ordinate academic requirements, employment, programme organisation, learner status, completed credit and return planning to support continuation and completion.
2. Supporting financial feasibility through targeted assistance	National STEM scholarships, Croatia; JSPS Restart Postdoctoral Research Fellowship, Japan	Reduce financial barriers to continued STEM study or return after interruption through accessible, predictable and appropriately targeted assistance.

1. Treating employment, interruption and re-entry as part of the educational route

When learners combine study with employment or temporarily interrupt their studies, formal permission alone does not provide a viable route to completion. Continued enrolment, interruption and delayed completion may reflect learners' circumstances and programme organisation rather than limited commitment or capacity. Learners need predictable scheduling, clear information about their status, recognition of completed learning, academic guidance and co-ordinated return planning.

Johannes Kepler University Linz's Study & Work programme provides a structured arrangement for combining higher education with employment. Participants work between 5 and 20 hours per week for a partner employer, starting from the third semester after completing the introductory and orientation phase, and are expected to complete at least 20 ECTS credits per semester. Employers adjust working hours around academic timetables, and workplace mentors help learners combine study with professional practice. Participants may receive three ECTS credits for relevant employment or work experience when this is provided for in the curriculum and accompanied by a reflective academic assignment (Reisinger, 2018^[45]).

The Study & Work programme connects income and professional experience with institutional and employer co-ordination. Employment may nevertheless compete with scheduled teaching, independent study, group work and support activities. Research involving employed master's learners at the university identified a need for more course options, fewer compulsory-attendance requirements, additional examination dates and appropriate multimedia provision (Reisinger, 2018^[45]). Monitoring should therefore examine participants' total workload, access to required courses and practical learning, credit accumulation, time to completion and subsequent progression. Comparison with learners combining study and employment outside the programme could help assess the contribution of structured co-ordination.

Germany's dual study programmes provide a more integrated model in which learners hold a contract with a partner employer and alternate between academic and workplace learning. Models differ in how they connect higher education, vocational qualifications and employment, but all require alignment of content, schedules, workload and assessment across the two settings (BIBB, 2024^[46]). Dual study can improve financial feasibility and provide recognised professional experience, but its longer-term value depends on whether workplace learning contributes to programme outcomes and whether learners retain options for further study and employment beyond the partner organisation. Monitoring should therefore examine completion, combined workload, substantive workplace learning, movement between employers and progression to further study (DIHK, 2026^[47]).

Where learners cannot continue studying alongside employment or other responsibilities, temporary interruption requires a different form of institutional support. Research at University College London treated interruption as a distinct stage in the learner's route rather than simply as withdrawal. Interviews found that learners could find interruption difficult to navigate even where it formally preserved the possibility of completion. Some were unaware of available support, while weak co-ordination created communication difficulties for learners and staff (Woods, 2024^[48]). Learners need assistance before, during and after interruption, including clear information about their academic and financial position, the status of completed learning, expected contact during leave and return procedures. Re-entry may also require an individual academic plan, adjusted pacing, refresher provision and renewed access to educators, mentors and programme communities.

Drawing on this work, UCL introduced redesigned digital processes for interruption and return in 2025. These combine historical records, learner-status information, communications, reminders, checklists and reporting. The university also provides for a Return to Study Plan and notifications to the learner, academic department and relevant services three months before the expected return date (University College London, 2025^[49]; University College London, 2025^[50]; University College London, 2025^[51]). These arrangements provide a common administrative basis for re-entry, but administrative improvement alone

does not establish that learners return, progress and complete. Monitoring should examine the timeliness of return planning, re-entry, recognition of completed credit, access to refresher provision and subsequent progression and completion. Administrative processes should remain connected with academic advice, financial guidance and learning support.

Together, the examples show that employment, interruption and re-entry can form part of a viable educational route when programme organisation accommodates them explicitly. Combining study and employment requires co-ordination of schedules, workloads, academic learning and workplace responsibilities. Interruption and return require reliable records, proportionate communication, clear responsibilities and co-ordination among academic, administrative, financial and learner-support functions. A central institutional process can preserve information and provide consistency, while programme-level academic input is needed to determine how previous learning relates to current requirements and what preparation and support are needed for return.

2. Supporting financial feasibility through targeted assistance

Financial assistance can make continued study or return after interruption feasible by reducing tuition, living, equipment and other participation costs and limiting the need for extensive paid employment. The examples show that financial assistance depends on its value, accessibility, predictability and duration, as well as its eligibility and continuation conditions.

Croatia's national STEM scholarship scheme illustrates how financial assistance can be connected with objectives concerning STEM participation and teacher supply. Under the arrangements implemented between 2017 and 2022, national student data were used to identify and rank eligible learners by field, level and year of study. Learners did not submit a separate application and were first contacted when informed of their eligibility, reducing informational and administrative demands (Filipović, 2026^[52]).

The scheme subsequently introduced a more highly funded track for learners in STEM teacher-education programmes in response to shortages of mathematics, science and other STEM teachers. During the period presented to the Mutual Learning Group, annual support amounted to EUR 5 400 for learners in STEM teacher education and EUR 2 700 for learners in other eligible STEM programmes. The scholarships operated alongside subsidised accommodation and meals for eligible learners (Filipović, 2026^[52]; Ministry of Science, Education and Youth, n.d.^[53]). The teacher-education track therefore connected the financial feasibility of individual participation with the capacity of school systems to provide STEM education.

The STEM scholarship scheme has since evolved. Under current arrangements, learners apply through the State Scholarship System following an annual public call, with separate lists for STEM teacher education and ranked lists by study level and year. Continuing recipients in STEM teacher education must meet conditions concerning regular enrolment in the subsequent year (Ministry of Science, Education and Youth, n.d.^[53]; Ministry of Science, Education and Youth, 2026^[54]). The change illustrates a design trade-off: applications can collect information unavailable in administrative records but reintroduce procedural demands, while continuation conditions may encourage progression but remove assistance when learners experience temporary difficulty.

Completion rates of approximately 87% to 90% were reported among scholarship holders during the 2017-22 funding period, with rates of approximately 85% to 90% in the subsequent period. The Ministry also reported that 219 learners supported through the three-year STEM and ICT scholarship project had entered employment in public primary or secondary institutions in fields experiencing shortages (Filipović, 2026^[52]). These figures describe outcomes among recipients but do not establish the additional effect of the scholarship. Recipients were selected partly through characteristics associated with study success, and no comparison with otherwise similar non-recipients was reported. Further analysis could examine whether financial assistance reduces financial pressure, extensive paid employment, interruption or time

to completion. These are the mechanisms through which financial constraints may affect participation and completion, as discussed in Chapter 1. Linking scholarship administration with longitudinal education and employment data could strengthen this evidence, subject to appropriate safeguards for learners' information.

Japan's JSPS Restart Postdoctoral Research Fellowship, introduced in 2006, supports doctoral-level researchers returning to research after an interruption of at least six weeks associated with childbirth or childcare (Japan Society for the Promotion of Science, n.d.^[55]; Japan Society for the Promotion of Science, 2025^[56]). Applicants do not need to be employed but must identify a host researcher and institution. The fellowship provides up to three years of financial support and access to research funding, giving researchers protected time and an institutional setting in which to resume their work.

The example shows that a formal opportunity to return may be insufficient where researchers lack income, resources or an institutional position. Financial assistance may therefore need to be combined with access to a suitable research environment. However, the requirement to identify a host may disadvantage applicants whose academic networks have weakened during their interruption. Although the fellowship concerns a return to advanced research rather than completion of an initial qualification, it illustrates how interruption can disrupt both the financial and institutional conditions required for return.

Together, the Croatian and Japanese examples show that the effects of financial assistance depend on more than the value of an award. Identification and application procedures affect who can obtain support, while eligibility, duration and continuation conditions determine whether it accommodates interruption and other non-linear routes. This reflects the Chapter 1 finding that formal availability of support does not necessarily make participation financially feasible. Where selection partly reflects previous attainment or other characteristics associated with success, evaluation should distinguish recipients' prior likelihood of completion from outcomes attributable to the assistance.

Lessons across the approaches

The examples show that financial assistance and flexible programme arrangements address different but connected barriers; ideally they are provided jointly. Funding can reduce tuition and living costs, financial shocks and the need for extensive paid employment. Flexible arrangements can help learners combine study with employment or care, adjust their study intensity, interrupt and return.

Together, these measures respond to the financial and practical barriers and non-linear educational routes discussed in Chapter 1. The design of assistance affects who receives support and whether it remains available during difficulty or interruption. Formal flexibility is useful only where learners retain access to required courses, laboratories, projects, educators, programme communities and coherent routes towards completion.

Employment can provide income, professional experience and opportunities to apply learning, but can also reduce the time available for study and support. Combined routes therefore require co-ordination among institutions and employers on schedules, workload, learning outcomes, assessment and mentoring. Workplace learning should develop disciplinary, interdisciplinary, transversal and professional competence and preserve progression and employment options beyond the partner organisation.

Transfer, interruption and re-entry can form part of a successful educational route rather than indicate failure. Institutions need to preserve relevant completed learning, explain learners' academic and financial status and provide clear arrangements for return. Re-entry may require an academic plan connecting recognised credit, targeted refresher or bridge provision and remaining programme requirements.

Public authorities can provide financial assistance, establish frameworks for credit recognition and learner protection, and support co-ordination among institutions, employers, funding bodies and social-support services. Higher education institutions remain responsible for programme coherence, academic standards,

recognition decisions and access to substantive learning. Monitoring should distinguish among continued enrolment, transfer, interruption, re-entry, delayed completion and permanent withdrawal, consistent with the limitations of aggregate completion indicators discussed in Chapter 1.

Policy Priority 2. Enable progression to advanced STEM expertise and skills renewal

Progression may involve movement between qualification levels, transition into research, movement into another specialisation or field, or return to education after a period in employment. These routes are not necessarily linear. Employment after an earlier qualification may be individually and socially valuable, while professional experience can provide a strong basis for later study and skills renewal.

As discussed in Chapter 1, access to research experience and skills renewal, suitable routes may be unclear, inaccessible or unaffordable. Learners may lack the preparation, research experience, recognition of previous learning, finance or institutional support needed to progress. These constraints can become a policy priority where they restrict equitable access to the development and renewal of advanced STEM skills and cannot be addressed by learners or individual institutions alone. Formal eligibility or the availability of a programme is insufficient if learners cannot understand or use the route in practice.

Public policy has a role where progression is constrained by fragmented responsibilities across education, research and employment; unequal access to research experience and financial support; inconsistent recognition of previous learning; or insufficient institutional and supervisory capacity. Public authorities can establish common frameworks, support co-ordination and recognition, and to strengthen teaching, research and supervisory capacity. Higher education institutions remain responsible for admission, curriculum, assessment, recognition decisions and the quality of programmes.

Three sub-priorities structure the analysis:

- make progression between educational levels and fields transparent
- widen equitable access to research experience and advanced study
- provide coherent skills-renewal routes for learners returning to higher education

2.1 Make progression between educational levels and fields transparent

Policy rationale, intended outcomes and risks

Progression to advanced STEM study can involve moving between qualification levels or fields, or returning to education after employment. Low immediate progression is not necessarily a problem if learners enter suitable employment and retain opportunities for further study. A bottleneck arises when avoidable barriers prevent learners from progressing, including unclear admission requirements, limited recognition of previous learning, unavailable preparation, geographical constraints, unexpected selection requirements or uncertainty about cost and duration. As Chapter 1 shows, progression rates alone do not reveal whether learners wanted to progress, could access a suitable route or encountered such barriers.

Public policy has a role because progression often crosses institutions, education sectors and qualification systems. Public authorities can provide qualification and credit frameworks, support recognition and preparatory provision, and promote timely and transparent decisions. Receiving institutions remain responsible for admission, recognition and academic standards.

Learners need clear information about entry requirements, recognised learning, additional preparation, competitive selection points, duration and cost. Formal eligibility does not always provide a usable route:

recognition may occur only after enrolment, required preparation may be unavailable, or access may depend on requirements that were not clear in advance.

Qualification, credit and competence frameworks can provide a common language for describing previous learning. Institutions still need to translate them into programme requirements, recognised credit and any additional preparation. Recognition and preparatory provision serve different purposes: recognition prevents unnecessary repetition of relevant learning acquired through education or work, while preparatory provision develops the foundations still required for the destination programme.

Progression from short-cycle to bachelor's education requires co-ordination between sending and receiving programmes. Movement into another field similarly requires recognition of existing competence and clear identification of any disciplinary, mathematical, scientific, computational or methodological foundations still needed. Diagnostic assessment can help identify these needs when it is connected with accessible preparation. Where possible, institutions can publish standard progression maps and predictable preparation options.

The intended outcome is clear and feasible movement between educational levels, employment and fields without unnecessary repetition, cost or delay. Learners should know what has been recognised, what remains to be completed and how the route leads to the intended qualification. Monitoring should examine access to and movement through these routes, including recognition decisions, required preparation, selection points, transfer, progression and differences across learner groups.

A potential unintended consequence is that measures intended to facilitate progression leave learners without the foundations or support needed to progress successfully. Recognising too much previous learning may leave essential gaps, while recognising too little may require learners to repeat relevant learning and incur unnecessary cost and delay. Late or inconsistent decisions may make it difficult to plan study and finance, while compressed or alternative routes may provide insufficient access to teaching, laboratories and learner support. Monitoring should therefore examine whether learners admitted through different routes receive the preparation and support needed to persist and complete.

Examples of interventions

Effective policy connects system-level frameworks with clear routes for individual learners. The following examples illustrate three connected approaches to making progression between educational levels and fields transparent: connecting recognition and competence frameworks with progression routes; providing transparent vertical progression from short-cycle to bachelor's education; and supporting horizontal movement through conversion programmes.

These approaches operate at different levels. Qualification, credit, recognition and competence frameworks provide common concepts for describing previous learning and intended destinations. Articulation arrangements translate these concepts into routes between programmes and qualification levels. Conversion programmes combine recognition of previous education with the foundations required to enter another field. Computer science provides a particularly relevant illustration of this third approach. Computing is increasingly important across scientific, technological and professional fields, and Chapter 1 shows that enrolment growth has been stronger in information and communication technologies than in engineering or the natural sciences. This growth includes learners seeking to move into computing after completing education in another field, creating a need for routes that recognise their existing competence while providing the computing foundations required for advanced study.

Table 2.5. Selected interventions to make progression between levels and fields transparent

Approach	Examples	Principal policy contribution
1. Connecting recognition and competence frameworks with progression routes	Lisbon Recognition Convention and European Credit Transfer and Accumulation System; UNESCO Global Convention on the Recognition of Qualifications concerning Higher Education; national recognition arrangements in Australia and New Zealand	Establish normative principles and common concepts for the fair and transparent recognition of qualifications, periods of study and prior learning, and support their translation into credit and programme-level progression arrangements.
2. Providing transparent vertical progression from short-cycle to bachelor's education	CTeSP provision and progression arrangements, University of Aveiro, Portugal; BrightStart, Portugal	Connect short-cycle and bachelor's provision through curriculum mapping, recognised credit, guidance, workplace learning and financial support.
3. Supporting horizontal movement through conversion programmes	Computer-science conversion and qualifying programmes in Ireland, New Zealand and Australia	Provide integrated, qualifying or differentiated routes into computing while making foundations, progression decisions, duration, cost and credit visible.

1. Connecting recognition and competence frameworks with progression routes

Learners progressing between educational levels or fields may seek recognition for academic or vocational education, workplace learning, professional practice or other non-formal and informal learning. In emerging and interdisciplinary fields, they may also need to compare their existing competence with educational and occupational profiles that do not correspond to a single established qualification route. As discussed in Chapter 1 in the sections on progression to advanced STEM study and the visibility of advanced STEM skills, difficulties in interpreting and recognising previous learning can make formally available routes unclear or difficult to use. Qualification, credit, recognition and competence frameworks can provide a common language for describing previous learning and intended destinations.

International conventions provide a normative basis for the recognition of qualifications and periods of study across national systems. The Convention on the Recognition of Qualifications concerning Higher Education in the European Region, commonly known as the Lisbon Recognition Convention, was adopted jointly by the Council of Europe and UNESCO in 1997 and has been ratified by all Council of Europe member states. It requires recognition authorities to use transparent, coherent and reliable procedures and establishes the principle that qualifications and periods of study should be recognised unless a substantial difference can be demonstrated. Recognition may provide access to further higher education, including preparation for doctoral study, and can also facilitate access to employment. The UNESCO Global Convention on the Recognition of Qualifications concerning Higher Education, adopted in 2019 and in force since 2023, extends common principles for fair, transparent, timely and non-discriminatory recognition across regions. It complements UNESCO's regional conventions and also covers qualifications, periods of study and prior learning acquired through different modes of provision (Council of Europe and UNESCO, 1997^[57]; UNESCO, 2019^[58]).

Within this framework, the European Credit Transfer and Accumulation System (ECTS) provides a common basis for describing learning outcomes and associated workload and supports the accumulation and transfer of credit across programmes, institutions and countries (Impola, 2024^[59]). ECTS can make the volume of completed learning more visible and facilitate comparison, but does not itself guarantee recognition, establish that courses are equivalent or determine whether credit contributes to the requirements of a particular destination qualification. These decisions remain the responsibility of the competent recognition authority or receiving institution, which must assess whether previous learning corresponds sufficiently to the content, level and outcomes of the receiving programme.

Australian and New Zealand illustrate how these principles can be implemented through national arrangements encompassing formal, non-formal and informal learning. Australian arrangements encompass credit transfer, articulation, advanced standing and recognition of formal, non-formal and informal learning. Decisions are based on evidence and academic judgement about the equivalence of

content and learning outcomes. Institutions must also consider whether granting credit would affect the learner's achievement of the expected outcomes or the integrity of the resulting qualification (TEQSA, 2023^[60]; Conrad, 2023^[61]).

New Zealand distinguishes between credit recognition and transfer, through which outcomes already achieved are recognised as credit towards comparable components of another qualification, and recognition of prior learning, through which relevant and current knowledge and skills are assessed against the outcomes of the destination programme. Prior learning may have been developed through formal education, non-formal learning or professional and other experience (NZQA, 2026^[62]).

The evidence required differs accordingly. Formal credit transfer can generally draw on transcripts, course information and documented learning outcomes. Recognition of workplace, professional or other non-credentialled learning may require a portfolio containing job descriptions, employer statements, reports, research or professional outputs, or another form of assessment demonstrating that the relevant outcomes have been achieved (NZQA, 2025^[63]).

These frameworks provide a system-level basis for recognition, but learners need to know how their previous learning applies to a particular destination. Where progression routes recur, institutions can publish the qualifications, courses or learning outcomes normally recognised; any additional evidence or bridge learning required; and the programme requirements that remain. Learners should also know when decisions will be issued, how they affect duration and cost, and how to obtain guidance or request a review.

Taken together, the examples show that international conventions, qualification and credit systems, and national recognition arrangements perform related but distinct functions. The Lisbon Recognition Convention and the Global Convention establish principles for fair, transparent and non-discriminatory recognition; qualification and credit systems support the description and comparison of learning; and national authorities and receiving institutions translate these principles and information into individual recognition and admission decisions. Their effectiveness depends on whether learners receive transparent programme requirements, timely and reasoned recognition decisions, accessible bridge provision and a clear route to a recognised qualification. These arrangements can help address the uncertainty, repetition and delay associated with progression routes identified in Chapter 1.

2. Providing transparent vertical progression from short-cycle to bachelor's education

Short-cycle programmes can prepare learners for employment while providing a route to further study. As the examples illustrate, a formal right to apply to a bachelor's programme does not by itself make that route usable. Learners need to know in advance how their previous learning will be recognised, which additional requirements apply, and how much time and cost remain.

Portugal's higher professional technical programmes, *Cursos Técnicos Superiores Profissionais* or CTeSP, lead to a European Qualifications Framework Level 5 diploma. They combine general and scientific learning, technical education and workplace training. The programmes are intended to have value in employment while also enabling graduates to apply to bachelor's programmes.

At the University of Aveiro, CTeSP provision illustrates the institutional arrangements required to make progression practicable (University of Aveiro, 2026^[34]). Programme-specific curriculum mapping can identify where CTeSP learning outcomes correspond to components of a bachelor's programme, which credits can be recognised and which disciplinary or methodological foundations remain to be developed. Guidance can explain how the short-cycle programme relates to possible destinations and whether learners need to select particular courses or workplace experiences to preserve their progression options.

Available institutional information indicates that the CTeSP programmes constitute substantial and assessed educational routes rather than collections of short courses. Approximately 76% to 82% of learners complete the programme within two years and a further 13% to 18% within three years, while

women represent around 22% of learners (University of Aveiro, 2026^[34]). These figures do not show how many graduates seek to progress, what credit they receive or whether they complete a bachelor's qualification. Consistent with the limitations of progression indicators discussed in Chapter 1, monitoring should distinguish graduates who enter employment by choice from those who seek further study but encounter barriers. It could then follow applications, recognition decisions, remaining study duration and completion across fields and learner groups.

BrightStart provides a structured five-year route connecting a two-year CTeSP programme with a subsequent three-year bachelor's degree. It combines formal education, workplace experience and tuition coverage and uses curriculum mapping to establish recognition between the two stages (Escola Superior de Tecnologia de Setúbal and Deloitte, 2018^[64]). Presenting the stages as a connected route can reduce uncertainty while preserving the qualification and employment value of the initial programme.

Employer participation can provide financial support, professional experience and a clear occupational context. However, the resulting learning and qualifications need to remain portable. Learners should understand whether recognised credit remains usable if they change employer, pursue another specialisation or apply to another institution. Monitoring should follow learners through both stages and distinguish planned completion with a short-cycle qualification from unsuccessful progression, transfer or withdrawal.

The examples show that transparent vertical progression requires more than a formal connection between qualification levels. Learners need programme-specific information about recognised credit, bridge requirements, the remaining route, costs and later options. Institutions need curriculum mapping, guidance, co-ordination and sufficient capacity in receiving programmes. Public policy should preserve both purposes of short-cycle education: preparation for employment and a practicable route to further study. Monitoring should follow learners through both stages and examine progression, completion, employment and further study. It should distinguish planned completion with a short-cycle qualification from unsuccessful progression or transfer to another educational or occupational destination, rather than treat low immediate progression as evidence of a bottleneck on its own.

3. Supporting horizontal movement through conversion programmes

The growing importance of computing across fields has created opportunities for graduates from other disciplines to move into computer science and related areas. Computing conversion programmes illustrate progression between fields, but should not be treated as a model for all STEM fields or as evidence that movement into computing should be prioritised in every context.

Learners may already hold an advanced qualification and possess substantial disciplinary, interdisciplinary, transversal and professional competence while lacking foundations in programming, algorithms, data structures, computer systems or software development. Conversion programmes seek to recognise relevant previous learning while providing the computing foundations required for advanced study.

Conversion programmes use three main models. Some integrate foundational computing into the destination master's programme. Others require a separate qualifying stage before application to the master's programme. A third approach varies programme length or grants advanced standing according to previous learning. These models have different implications for admission, credit, duration, cost and access to the destination qualification.

The University College Dublin MSc Computer Science Conversion provides an integrated route for graduates from other fields. The 16-month programme leads to a Level 9 qualification and does not require previous programming experience. Foundational computing forms part of the master's programme rather than a separate admission requirement. This makes the destination qualification and overall duration clear,

but requires careful sequencing from introductory computing to master's-level learning (University College Dublin, 2026^[65]).

Technological University Dublin's Computing Fundamentals Masters Qualifier uses a separate qualifying model. Learners complete specified computing modules and must pass the required components with an average of 60% to become eligible to apply to the associated master's programme (Technological University Dublin, n.d.^[66]). This allows learners to develop and demonstrate the required foundations before advanced study, but successful completion does not necessarily guarantee admission. Learners therefore need to know whether the qualifying stage leads directly to the master's programme, how it is recognised if they do not progress, and how it affects total duration and cost.

The Master of Information Technology programmes at the University of Auckland and the University of Waikato use routes of 120, 180 or 240 points according to entrants' previous education. This differentiated model recognises relevant previous study while providing more extensive foundational learning for learners without a computing background (University of Auckland, 2026^[67]; University of Waikato, n.d.^[68]). It can prevent unnecessary repetition, but learners need a timely decision explaining which previous learning has been recognised, why they have been assigned to a particular route and which components remain.

UNSW Sydney's Master of Information Technology provides a two-year programme with possible advanced standing for learners with relevant previous computing study (UNSW Sydney, 2026^[69]). This retains a common programme structure while reducing its duration where previous learning meets programme requirements. Its value depends on predictable criteria and timely decisions about which academic education, professional certification or workplace learning will be recognised. Institutions should also examine whether learners receiving advanced standing encounter gaps in later courses that require changes to recognition decisions or targeted preparation.

The examples show that movement between fields can be supported through integrated, qualifying or differentiated routes. Their suitability depends on learners' previous competence, the foundations required by the destination qualification and the institution's capacity to provide well-sequenced learning and support. Learners should know whether they are entering the destination qualification or a preparatory stage, whether completion of that stage guarantees progression, what previous learning is recognised, and the total duration and cost. Monitoring should examine access, progression and completion across routes and learner backgrounds, as well as whether recognition decisions leave gaps or require unnecessary repetition.

Lessons across the approaches

The examples show that system-level frameworks produce equitable progression only when institutions translate them into clear and usable routes for individual learners. Qualification, credit, recognition and competence frameworks can describe previous learning and possible destinations, but learners need timely information about admission, recognised credit, additional preparation, selection points, duration and cost.

Recognition and bridge provision have complementary roles. Recognition prevents unnecessary repetition by identifying relevant learning already achieved through education or professional experience. Bridge provision develops the foundations still required by the destination programme. Too little recognition increases cost and delay, while too much may leave learners unprepared for advanced study.

Progression may occur between qualification levels, between education and employment, or across fields. Articulation agreements and curriculum mapping can connect short-cycle and bachelor's programmes while preserving the employment value of the initial qualification. Conversion programmes can recognise competence developed in another discipline while providing the foundations required by the destination field. Neither form of progression needs to be immediate or continuous.

Formal eligibility alone does not make a route usable. Late recognition decisions, unavailable bridge provision, unexpected competitive selection points and unclear allocation rules can create uncertainty and delay. Receiving institutions also need sufficient teaching, infrastructure and learner-support capacity. Monitoring should distinguish learners who do not seek immediate progression from those who wish to progress but encounter these barriers, consistent with the limitations of progression indicators discussed in Chapter 1.

2.2 Widen equitable access to research experience and advanced study

Policy rationale, intended outcomes and potential risks

Research experience can help learners understand how knowledge is produced, develop advanced disciplinary and methodological competence, and determine whether research-oriented study suits their interests. It can also support entry to postgraduate study and provide access to supervisors, research communities and professional opportunities. However, these opportunities are unequally distributed. Access may depend on informal contacts, unadvertised positions or unpaid work, favouring learners at research-intensive institutions or those with strong networks and the financial and geographical flexibility to participate. Learners who work, study part time, transfer between institutions or lack familiarity with academic systems may face greater barriers.

Widening access requires opportunities to involve substantive research rather than participation alone. Experience in a laboratory or project does not establish that learners have contributed to research design, evidence collection, analysis, interpretation or communication. Clear learning objectives, suitable supervision, increasing responsibility and opportunities to demonstrate learning are therefore essential. Research embedded in courses can reach learners who might not obtain separate opportunities, while paid placements can support longer participation. Partnerships and mobility can provide access to specialist environments unavailable at a learner's home institution, and cross-sector doctoral arrangements can connect advanced research with different professional settings. The appropriate approach depends on the barriers identified and the learners and institutions affected.

Funding, selection and institutional capacity determine whether these opportunities are accessible and effective. Funding may need to cover travel, relocation, accommodation, equipment, care and disability-related support as well as participation itself. Transparent selection can reduce reliance on networks, confidence and familiarity with academic systems. Expansion also needs to be matched by research and supervisory capacity. Increasing placements or doctoral positions without adequate supervision, research support and doctoral teaching may weaken quality. Capacity planning should therefore consider supervisory preparation and workload, access to research communities and support when difficulties arise.

Public policy has a role because research experience contributes to wider research and innovation capacity and depends on infrastructure, funding and supervision that individual learners cannot secure alone. Public authorities and research funders can support research within programmes, paid placements, mobility, institutional partnerships and funded doctoral routes. Higher education institutions and research organisations remain responsible for selection, supervision, research quality and the educational value of participation. Unequal access should also inform how previous research experience is interpreted in postgraduate admissions. Admissions should consider the substance and quality of applicants' experience in relation to the opportunities available to them, without compromising academic standards. A lack of conventional research experience does not necessarily indicate limited potential.

The intended outcome of policy intervention is equitable access to connected routes from initial research experience to advanced study and employment. Learners should be able to undertake substantive research and demonstrate their competence without depending mainly on informal networks, unpaid work or attendance at a research-intensive institution. Monitoring should examine who applies, participates and progresses; the substance and duration of the experience; access to supervision and research

communities; and subsequent entry to advanced study or relevant employment across learner groups and institutions.

The main risk is that measures widen participation without providing equitable or substantive research experience. Opportunities may remain concentrated among learners and institutions already connected to research, while some participants may receive routine tasks rather than meaningful research responsibilities. Expansion may also overstretch supervisory capacity and weaken guidance and feedback. In cross-sector arrangements, unclear responsibilities or excessive emphasis on organisational priorities may narrow research agendas or weaken academic independence. Monitoring should therefore establish whether wider participation is accompanied by substantive responsibilities, appropriate supervision, research quality and academic independence, and whether the competence developed remains useful across educational, research and professional settings.

Examples of interventions

The examples illustrate four connected approaches to widening equitable access to research experience and advanced study: embedding research experience within the curriculum; funding substantive research participation; strengthening research environments and widening access through partnerships and mobility; and connecting doctoral education with cross-sector research.

These approaches differ in their intensity and position along the route to advanced study. Course-based research can provide broad initial access. Funded placements can enable more sustained participation, with support provided by public authorities, research funders, higher education institutions or employers. Partnerships and mobility can connect learners with research environments and infrastructure not available at their home institution. Cross-sector doctoral programmes can support advanced research across academic and professional settings.

Table 2.6. Selected interventions to widen access to research experience and advanced STEM study

Approach	Example	Principal policy contribution
1. Embedding research experience within the curriculum	Course-based Undergraduate Research Experiences, United States	Extend introductory research participation beyond learners able to obtain selective opportunities through informal relationships or unpaid activity outside the curriculum.
2. Funding participation in substantive research	Undergraduate Student Research Awards, Canada; Undergraduate Research Opportunities Program, Australia; Verão com Ciência, Portugal	Reduce financial barriers and enable sustained participation in supervised research, supported where necessary by assistance with travel, accommodation and other participation costs.
3. Strengthening research environments and widening access through partnerships and mobility	BK21 FOUR, Korea; BUILD PODER, United States; NIMS Internship Program, Japan	Connect learners with research teams, mentors, facilities and wider research communities while strengthening institutional research and supervisory capacity.
4. Connecting doctoral education with cross-sector research	Centres for Doctoral Training, United Kingdom; CIFRE, France; Industrial PhD, Denmark	Combine advanced research education with thematic cohorts, sectoral applications, complementary supervision and experience across academic and non-academic research environments.

1. Embedding research experience within the curriculum

Course-based Undergraduate Research Experiences, or CUREs, are an established approach to widening participation in undergraduate research, particularly in the biological sciences. They incorporate original or authentic research activity into regular STEM courses. Course-based Undergraduate Research Experiences, or CUREs, incorporate original or authentic research activity into regular STEM courses. Unlike selective placements undertaken outside the curriculum, they can make initial research experience available to a broader group of learners as part of their enrolled study. Learners may contribute to research

questions, evidence collection, analysis, interpretation and communication, although the depth and organisation of these activities vary among courses.

As discussed in Chapter 1 in the sections on access to research experience and progression to advanced STEM study, opportunities obtained through informal contacts, separate applications or unpaid work may favour learners with stronger networks and greater financial flexibility. Embedding research within the curriculum can reduce reliance on learners approaching individual academics, obtaining informal recommendations or undertaking unpaid activity alongside their studies. It can therefore widen access for learners with limited academic networks, little time for additional activities or insufficient financial flexibility to accept unpaid positions. Its contribution to equitable participation nevertheless depends on whether all learners engage in substantive conceptual and methodological work rather than being allocated routine or peripheral tasks.

Evidence from CUREs involving more than 2 500 learners in the United States associates participation with gains in interdisciplinary thinking, science identity and intentions to continue in STEM, including among learners from groups historically under-represented in science (Rosenblum et al., 2025^[70]). Research covering approximately 1 500 learners, 22 educators and 19 institutions also indicates that sustained, course-long experiences may produce stronger outcomes in experimental design and research-related career interest than shorter forms of exposure (DeChenne-Peters et al., 2023^[71]).

These findings suggest that the duration and substance of participation matter. They do not establish that all course-based research produces similar effects or that changes in identity and intentions lead to progression to advanced study. Assessment within the course can examine whether learners develop the intended research competence, while longitudinal monitoring can follow subsequent participation in research, applications to postgraduate education and progression into research-related careers.

Research questions, teaching practices and the recognition of learners' contributions can also affect whose work receives attention and support. As Chapter 1 notes, unequal access to opportunities can be compounded by unequal recognition of the advanced STEM skills demonstrated through them. Inclusive curriculum design can draw on varied questions and perspectives and recognise the knowledge and experience that learners bring, rather than treating familiarity with established academic conventions as a condition for participation (Hofstra et al., 2020^[72]). Research on doctoral recipients in the United States also indicates that novel contributions by researchers from under-represented groups may be less likely to be recognised and associated with academic careers, showing that inequalities may persist after access has been widened (Hofstra et al., 2020^[72]; Kozłowski et al., 2022^[73]).

Research questions, teaching practices and the recognition of learners' contributions can also influence who experiences research as inclusive and relevant. Inclusive curriculum design can draw on varied questions and perspectives and recognise the knowledge and experience learners bring, rather than treating familiarity with established academic conventions as a condition for participation (Hofstra et al., 2020^[72]). This is important because unequal recognition may continue after access has been widened. Analysis of approximately 1.2 million doctoral recipients in the United States found that researchers from under-represented groups produced higher rates of scientific novelty, while their novel contributions were less likely to be taken up and associated with academic careers, a pattern described as a diversity-innovation paradox (Hofstra et al., 2020^[72]). Research priorities and recognition practices may therefore shape whose contributions receive attention and support as well as who participates (Kozłowski et al., 2022^[73]).

Course-based research requires educator preparation, curriculum design, laboratory or data infrastructure, technical support and sufficient time for feedback and supervision. Expanding participation without these capacities may increase the number of learners formally exposed to research without giving them substantive roles or opportunities to develop increasing autonomy. Public funding can support the incorporation of research into regular teaching, while institutions remain responsible for the educational quality and assessment of the experience.

2. Funding participation in substantive research

Sustained placements can enable learners to engage more deeply with research questions, methods and communities than is normally possible within a single course. They respond to the unequal access to substantive research experience identified in Chapter 1, but may remain inaccessible where positions are unpaid or where learners must meet additional travel, accommodation, equipment, dependent-care or disability-related costs. Public funding can reduce these barriers while supporting transparent selection, appropriate supervision and substantive participation.

Canada's Undergraduate Student Research Awards support learners undertaking supervised research in universities and eligible research settings. The awards generally support placements lasting 14 to 16 weeks and provide a contribution of CAD 6 000, supplemented where applicable by the host institution. More than 3 000 awards are offered annually across the relevant federal research programmes (NSERC, 2026^[74]). The awards establish a nationally recognised mechanism through which learners can obtain sustained research experience and financial support.

The funding can reduce the cost of foregoing other employment, but access also depends on how learners obtain information, identify supervisors and prepare applications. Selection based heavily on grades, previous research experience or informal academic support may favour learners who already have stronger preparation and networks. This can reproduce the unequal access to opportunities for developing and demonstrating advanced STEM skills discussed in Chapter 1. Transparent advertising, contextual consideration of previous opportunities and practical support with applications may therefore be as important as the value of the award.

Australia's Undergraduate Research Opportunities Program provides paid research placements lasting between six and twelve months. It connects undergraduate learners with research organisations and enables them to participate in sustained projects alongside experienced researchers (CSIRO, 2026^[75]). The longer duration may allow learners to move beyond initial observation or technical assistance and develop a stronger understanding of research design, uncertainty and the iterative character of scientific work.

The involvement of an intermediary organisation can help identify projects, connect learners and supervisors and establish expectations for participation. This may be particularly useful where learners or host organisations lack established relationships. The educational value of a longer placement nevertheless depends on whether learners' responsibilities increase over time, regular feedback is provided and the experience is connected with their academic learning and future educational or occupational options.

Portugal's *Verão com Ciência* (Summer with Science) initiative used publicly funded scholarships to widen participation in summer research activities. It provided EUR 3.4 million for 2 353 scholarships, enabling learners to participate in research projects and become familiar with scientific institutions and research careers (FCT, 2026^[76]). The initiative illustrates how public funding can expand opportunities across institutions and fields within a defined period.

The objectives and outcomes of short summer activities may differ from those of longer placements. Some participants may gain an initial understanding of research environments, while others may undertake more substantial methodological and analytical work. The number of scholarships therefore demonstrates reach but does not indicate the depth or educational value of participation.

Across the three examples, funding can make research participation materially possible but does not by itself guarantee equitable selection or educational quality. Effective arrangements require transparent advertising, application and allocation processes, sufficient remuneration, support for additional participation costs, clear learning objectives and appropriate supervision. Monitoring should establish whether funding reduces the financial, geographical and informational barriers identified in Chapter 1. It

should also examine who receives funding, how learners are selected, the responsibilities they undertake, the competence they develop and whether participation leads to further research experience, postgraduate study or relevant employment.

3. Strengthening research environments and widening access through partnerships and mobility

Access to research experience depends partly on the research capacity of the institution a learner attends, including its laboratories, funded projects, active research groups, supervisors and academic networks. Partnerships and mobility can connect learners with research environments unavailable at their home institution, while institutional investment can expand opportunities within the home institution. Combining these approaches can widen immediate access while strengthening institutions' longer-term capacity to provide research experience.

Korea's BK21 FOUR initiative, the fourth phase of the Brain Korea 21 programme, illustrates sustained national investment in postgraduate research education and institutional capacity. Implemented between 2020 and 2027, it supports 602 education and research teams across 63 universities, providing support for postgraduate learners, research teams and institutional research environments (Korea University, n.d.^[77]; National Research Foundation of Korea, 2026^[78]). Its scale and duration allow investment in research teams, supervision and institutional capacity beyond individual placements. Its contribution to widening access nevertheless depends on how funding and opportunities are distributed across institutions, fields, teams and learner groups. The number of participating universities, teams and learners demonstrates implementation but does not establish the quality of supervision, competence development or progression into sustainable research careers. Monitoring should therefore examine these outcomes and whether institutional capacity continues after the funding period.

BUILD PODER in the United States illustrates a more targeted approach that combines research participation, mentoring and institutional development. The initiative involved 81 learners and 41 mentors and sought to strengthen biomedical research participation and progression among groups historically under-represented in research. It combined research training, mentoring and academic development with changes intended to create a more supportive research environment (Ashcroft et al., 2021^[79]). This approach recognises that widening access cannot depend only on preparing individuals to enter institutions that remain difficult to navigate. Direct opportunities for learners need to be accompanied by changes in mentoring, faculty practice and the allocation of research opportunities. Because the intervention combined several components, their individual contributions are difficult to isolate. Longer-term monitoring should examine progression into postgraduate study and research careers alongside changes in institutional mentoring capacity, faculty practice and access to research opportunities.

Japan's National Institute for Materials Science Internship Program provides a third approach by connecting learners with specialist infrastructure and an international research environment. It hosts approximately 100 interns each year and has received more than 2 000 participants since 2006. Learners work with NIMS researchers and gain experience of advanced materials-science research, facilities and methods (NIMS, 2026^[80]). Such mobility can provide opportunities unavailable at a learner's home institution, expand academic networks and introduce learners to different research environments. However, travel, accommodation, language, immigration procedures, disability-related requirements and care responsibilities may restrict participation. Monitoring should therefore examine who participates, the responsibilities and supervision provided, assessed learning and subsequent progression. Financial assistance, orientation and accessible supervision can help make the opportunity usable by a wider range of learners.

Together, the examples show that mobility and partnerships can complement but should not replace institutional capacity-building. Sending selected learners to research-intensive environments may widen individual opportunities without improving access for those who remain at their home institutions.

Partnerships can produce broader benefits when they include faculty collaboration, shared supervision, staff development, common courses, remote access to facilities and research-based teaching. Policy therefore needs to address both unequal individual access to research experience and differences in the institutional capacity to provide it.

4. Connecting doctoral education with cross-sector research

Doctoral education develops the capacity to conduct original research and can prepare graduates for academic research, technological development and advanced professional roles. Partnerships with employers, public organisations and other sectors can connect doctoral research with practical problems, specialist infrastructure and a wider range of careers. They can also address the constraints discussed in Chapter 1 concerning access to suitable supervision, research environments and opportunities to apply and demonstrate advanced STEM skills. These arrangements need to preserve the depth, quality and independence of doctoral education while co-ordinating academic and organisational responsibilities.

The United Kingdom's Centres for Doctoral Training provide structured doctoral education organised around thematic areas and learner cohorts. In 2024, UK Research and Innovation announced approximately GBP 1 billion in investment involving 65 centres. The model combines doctoral research with structured learning, cohort participation, engagement with external partners and, in some cases, access to shared facilities and placements (UKRI, 2024^[81]; UKRI, 2026^[82]).

Centres for Doctoral Training can create critical mass in specialised and interdisciplinary fields, provide access to a wider range of academic and professional expertise and reduce dependence on an individual supervisory relationship. Cohort-based provision may also reduce isolation and support learning across projects and disciplines. These benefits depend on sufficient supervisory capacity, appropriate project allocation and equitable recruitment.

The number of centres, funding and doctoral places demonstrates substantial public investment but does not establish the quality or additional effects of the model. Monitoring should examine completion, time to degree, research quality, learner well-being, competence development and employment across sectors. Comparison with other doctoral routes could help identify whether structured learning, cohort participation and complementary supervision address possible supervisory and institutional constraints.

France's Industrial Agreements for Training through Research, or CIFRE, connect a doctoral researcher with a company or other eligible organisation and an academic research laboratory. The external organisation employs the doctoral researcher, while the research is jointly supervised and contributes to a recognised doctorate. More than 30 000 doctoral researchers have completed the route since its creation, and approximately 1 500 to 2 150 new agreements have been supported annually in recent years (Ministry for Higher Education, Research and Space, n.d.^[83]).

CIFRE provides income, an employment setting and access to both academic and organisational expertise. It can also help participating organisations develop research capacity and enable doctoral researchers to understand how advanced knowledge is developed and applied outside higher education. The scale and continuity of CIFRE demonstrate that cross-sector doctoral education can become an established national route rather than remain a collection of temporary partnerships.

Completion and employment outcomes provide important information but do not establish how the route affects research quality, competence development or longer-term careers compared with other doctoral arrangements. Monitoring should examine progression, time to completion, research and publication outcomes, academic integration, well-being, subsequent mobility across sectors and the continued use of advanced research competence. It should also account for differences in doctoral candidates' previous education, professional experience and employment circumstances when interpreting outcomes (Haley, Holmqvist and Johansson, 2024^[84]; Martínez-García et al., 2024^[85]; Compagnucci and Spigarelli, 2024^[86]). Clear agreements are needed on supervision, protected research time, doctoral education, publication,

confidentiality, intellectual property and the resolution of disagreements. Cross-sector routes may also enable experienced professionals to develop advanced research competence grounded in prior professional experience, but their circumstances should not be treated as equivalent to those of candidates entering directly from earlier study.

Denmark's Industrial PhD programme similarly connects a doctoral candidate, a private-sector organisation and a public research institution. Innovation Fund Denmark provides financial support, while the candidate undertakes a research project relevant to the organisation and meeting the academic requirements of a doctorate. The model is intended to strengthen knowledge exchange and research capacity across higher education and industry (Innovation Fund Denmark, 2025^[87]).

The arrangement can give doctoral candidates access to complementary supervisors, research facilities in industry and professional environments. However, it may also create tensions between academic and organisational priorities. Candidates need appropriate remuneration and employment conditions, protected time for research and doctoral education, while expectations concerning confidentiality, publication, intellectual property and changes to the project should be agreed in advance (OECD, 2026^[88]).

The examples illustrate different ways of connecting doctoral education with wider research and professional environments. Participation and completion demonstrate implementation, but assessment should also examine the independence and quality of the research, supervision, competence development, doctoral candidates' experience and subsequent careers. Monitoring should determine whether candidates develop advanced research competence and can apply it across academic and professional settings. Complementary supervision and clear governance are needed to prevent candidates from being used primarily to deliver short-term organisational projects. These conditions respond to the supervisory, institutional and career-progression constraints identified in Chapter 1.

Lessons across the approaches

The examples show that widening access to research requires connected opportunities at different stages. Course-based research can provide early experience, funded placements can support deeper participation, partnerships and mobility can open access to specialist facilities, and doctoral programmes can connect advanced research with different professional settings. Together, these approaches respond to unequal access to research opportunities, supervision, infrastructure and networks identified in Chapter 1.

Access alone is not enough. Learners need substantive roles in research design, evidence collection, analysis, interpretation and communication rather than routine tasks. Clear objectives, effective supervision, regular feedback and increasing responsibility help them develop and demonstrate disciplinary, interdisciplinary, transversal and professional competence. Embedding research in the curriculum can reduce reliance on informal contacts, unpaid work and activities outside regular study, but requires sufficient educators, technical staff, infrastructure and supervision time. Without this capacity, wider participation may provide only limited research experience.

Funding can support sustained participation by replacing forgone earnings and covering travel, accommodation, equipment, dependent care and disability-related costs. Employers and other external partners may complement public funding through scholarships, paid placements, access to facilities and staff time for supervision. Transparent advertising, accessible applications and consideration of learners' previous opportunities are also needed to prevent selection from favouring those who already have research experience or strong academic networks. This is particularly important where previous research experience is later treated as evidence of ability or potential for advanced study.

Partnerships among higher education institutions, research organisations and employers can widen access to specialist expertise, facilities, research environments and applied problems that may not be available at a learner's home institution. Shared courses, staff development, joint supervision and remote

access to facilities can also strengthen institutional research capacity and extend the benefits beyond direct participants. Without these wider connections, opportunities may remain concentrated among learners and institutions already well connected to research.

Clear responsibilities are essential for effective partnerships. Higher education institutions and research organisations remain responsible for academic standards, research quality and the educational coherence of the experience. Employers providing placements, facilities or co-supervision should offer substantive research work, suitable supervision, feedback and appropriate remuneration. Agreements should clarify learning and research objectives, supervision, access to data and infrastructure, publication, confidentiality, intellectual property and how the competence developed can be demonstrated and used beyond the partner organisation.

Cross-sector doctoral programmes apply these principles at an advanced level by connecting research with public, private and other professional settings. Their quality depends on appropriate remuneration, protected research time, complementary supervision and clear agreements on academic standards, publication, confidentiality, intellectual property and research independence. Doctoral candidates should be able to develop and apply advanced research competence rather than serve primarily as personnel for short-term organisational projects.

Expansion must be matched by research and supervisory capacity. Increasing placements or doctoral positions without prepared supervisors, suitable infrastructure and functioning research communities may weaken quality or delay completion. Capacity planning should therefore consider the quality and workload of supervision, not only the number of opportunities created.

Public authorities and research funders can support curricular research, paid placements, mobility, institutional partnerships, infrastructure and doctoral positions. They can also establish expectations for transparent selection, adequate remuneration and monitoring. Higher education institutions, research organisations and participating employers retain responsibility for research quality, supervision, substantive participation and academic standards.

Monitoring should examine who can access research experience, the substance and duration of participation, the quality of supervision, the competence developed and subsequent progression into advanced study, research or relevant employment. It should also determine whether interventions reduce inequalities in individual access and institutional research capacity or mainly expand opportunities for learners and institutions already well placed to participate.

2.3 Provide coherent skills-renewal routes for learners returning to higher education

Policy rationale, intended outcomes and potential risks

Changes in scientific knowledge, technology, methods, regulation and professional practice create continuing needs for skills renewal. In this report, skills renewal covers updating or deepening existing advanced STEM skills, movement into an adjacent field and more substantial occupational change. These objectives require learning of different depth, breadth and duration.

Individuals seeking skills renewal and returning to higher education differ in their previous education, professional experience, current competence and intended destinations. Recent STEM graduates may seek specialised updating, experienced professionals may move into an adjacent field, graduates from other fields may seek to enter STEM-related work, and adults without previous higher education may bring relevant competence developed through vocational education or employment. Existing data do not always show what learners seek to achieve, what competence they already possess or whether available provision offers a usable route to their intended destination.

Skills-renewal routes need to reflect learners' different starting points and destinations. Providers should specify the previous knowledge required, the purpose, level and scope of the learning, the competence assessed and the educational or occupational opportunities that follow. Provision designed for experienced STEM professionals may be unsuitable for learners entering from another field, while requiring experienced professionals to repeat extensive foundational learning may create unnecessary cost and delay. Recognition can identify relevant academic, vocational, professional and workplace learning already achieved, while diagnostic assessment can identify essential foundations that remain to be developed. Bridge or refresher provision can then address these needs rather than impose the same sequence on every returning learner.

Short courses and micro-credentials can support focused updating and make specialised competence more visible. Their value depends on clear learning outcomes, credible assessment, quality assurance and recognition by institutions, employers and professional bodies. They provide only a partial response where learners require cumulative disciplinary learning, advanced methods, practical experience or the integration of disciplinary, interdisciplinary, transversal and professional competence. Several individually useful courses do not automatically form a coherent route. Where shorter components are intended to contribute to a larger qualification, the route should specify prerequisites, level, credit, learning outcomes, assessment, sequencing, recognition responsibilities, integrative learning and the destination qualification. Accumulation should represent coherent progression in learning rather than the numerical addition of credits.

Flexible delivery can improve access for learners combining education with employment, care and other responsibilities, but flexibility in format does not necessarily make provision usable. Evening, weekend, hybrid, online, part-time and regional provision may need to be combined with predictable schedules, employer permission, paid learning time, financial assistance and support with travel or care. Learners must also retain access to specialist educators, laboratories, equipment, collaborative learning, feedback and academic communities where these are required.

Public policy has a role where fragmented provision, unclear recognition, high costs, limited employer support or arrangements designed mainly for full-time learners restrict participation. Skills renewal may also benefit employers, sectors and society beyond the individual learner. Public authorities can support information, finance, quality assurance, recognition and co-ordination across providers, while higher education institutions remain responsible for admission, programme design, assessment, recognition decisions and qualification standards.

The intended outcome is a set of navigable and recognised routes corresponding to different forms of skills renewal. Learners should understand how their previous education and professional experience connect with their intended destination, what will be recognised and what learning remains necessary. Employers and receiving institutions should be able to interpret what a course, micro-credential or qualification certifies. Monitoring should examine learners' starting points and objectives, who seeks and enters provision, recognition decisions, progression across components and subsequent educational and employment outcomes. It should also assess whether adults with different employment, financial, geographical and personal circumstances can use these routes in practice.

A potential risk is that measures expand the number of courses without creating coherent and usable routes. Learners may complete disconnected components that lack clear recognition, essential disciplinary foundations or a defined relationship with further education or employment. Flexible provision may remain difficult to use because of scheduling, cost, limited employer support or inadequate access to specialist teaching and infrastructure. Temporary funding may expand provision without establishing sustainable recognition and progression arrangements, while employer-dependent provision may exclude workers receiving little organisational support or focus learning too narrowly on immediate organisational needs. Monitoring should therefore examine whether provision forms coherent and sustainable routes, preserves

essential foundations, is recognised across institutions and employers, and remains accessible and useful beyond a single organisation.

Examples of interventions

The examples illustrate two connected approaches to providing coherent skills-renewal routes in higher education. The first approach concerns how emerging competence needs can be identified and translated into provision for learners with different starting points and objectives. The second concerns the institutional and system arrangements through which short, credit-bearing learning can form part of a longer educational route.

Table 2.7. Selected interventions providing coherent skills-renewal routes through higher education

Approach	Example	Principal policy contribution
1. Connecting competence frameworks, flexible provision and occupational profiles in emerging fields	AI4Health.Cro, Croatia; European Competence Framework for Quantum Technologies; Quantum Programming Foundations, University of Galway, Ireland; Integrated Quantum Photonics, University of Málaga, Spain; Quantum Valley Lower Saxony, Germany	Distinguish competence needs and connect them with provision supporting focused updating, deeper specialisation and movement into adjacent fields.
2. Enabling shorter learning to accumulate towards larger qualifications	<i>Impulso Adultos</i> (Impulse for Adults) and University of Aveiro micro-credentials, Portugal; Human Capital Initiative MicroCreds, Ireland	Expand quality-assured, credit-bearing provision and develop the information, sequencing and recognition arrangements through which shorter components can contribute towards larger qualifications.

1. Connecting competence frameworks, flexible provision and occupational profiles in emerging fields

In emerging fields, where technologies, methods, laws and regulations, and professional applications develop rapidly, skills-renewal routes are particularly important. Tailored approaches are needed, as the examples illustrate. For example, a healthcare professional seeking to understand artificial intelligence in clinical practice has a different starting point from a computing specialist developing healthcare applications or a professional moving into health data science. Provision should therefore specify whether it supports focused updating, deeper specialisation, movement into an adjacent field or more substantial occupational change. It should also make clear the previous knowledge required, the level and volume of learning, the competence developed and assessed, and the relationship with further learning or occupational responsibilities.

AI4Health.Cro, a European Digital Innovation Hub in Croatia, illustrates a sector-oriented approach connecting artificial intelligence, high-performance computing, digital healthcare, innovation, business and regulation. It offers workshops, micro-credentials, academic modules, internships and other practical opportunities for medical learners, healthcare professionals and technical specialists (AI4Health.Cro, n.d.^[89]). This range reflects the different competence required to develop, introduce and use AI in healthcare, including clinical applications, data governance, regulation, organisational implementation, ethical responsibilities and the limitations of AI-supported decisions. Depending on their role, learners may therefore need different combinations of disciplinary, interdisciplinary, transversal and professional competence.

The breadth of the offer makes clear differentiation important. A short awareness workshop does not provide the same depth as an assessed academic module, micro-credential or supervised internship. Learners, employers and receiving institutions need to understand what each component certifies and how it relates to further learning and professional responsibilities. Monitoring should therefore examine

assessed learning, progression to further education, changes in occupational responsibilities and the application of renewed competence in healthcare settings, rather than participation and completion alone.

Quantum technologies provide another example of differentiated needs in an emerging interdisciplinary field. The field draws on physics, mathematics, computing, engineering and application-specific knowledge, while its roles require different combinations and levels of competence. Some learners may need enough understanding to assess the relevance of quantum technologies to their organisation, while others may need to develop quantum software, hardware or applications.

The European Competence Framework for Quantum Technologies helps make these differences visible. It identifies eight competence domains, 42 subdomains, six proficiency levels and nine qualification profiles, helping providers relate programme content to emerging roles and learners and employers compare existing competence with possible educational or occupational destinations (European Commission, 2025^[90]). The framework does not itself provide a skills-renewal route, determine admission, assess previous learning, award credit or guarantee recognition. Its contribution depends on whether providers use it to define prerequisites and learning outcomes, distinguish introductory awareness from advanced competence, design assessment and connect competence profiles with recognised courses, qualifications and occupational roles. Public authorities and intermediary organisations can support this translation by bringing together education providers, employers, research organisations and professional bodies.

Short, credit-bearing provision shows how these distinctions can be translated into particular learning opportunities. The University of Galway's Quantum Programming Foundations micro-credential is a 12-week course at Level 8 of Ireland's National Framework of Qualifications carrying five ECTS credits. It provides a defined option for learners seeking computing-related competence in quantum technologies without immediately undertaking a full qualification (University of Galway, 2026^[91]). The University of Málaga's Integrated Quantum Photonics micro-credential is a more specialised three-ECTS course requiring a previous STEM background and is intended to extend existing scientific or technical competence (University of Málaga, 2026^[92]).

These examples show why micro-credentials in the same field should not be treated as interchangeable. They differ in assumed knowledge, technical focus, level, volume and intended contribution to skills renewal. Information on these features can help learners identify provision suited to their starting point and objective and help employers and receiving institutions interpret what completion demonstrates. Credit and qualification levels make the scale of learning more visible but do not show whether it contributes to a larger qualification or professional route. Learners also need to know which programmes recognise the credit, whether additional foundations are required and which further educational or professional opportunities follow.

Regional co-ordination can help connect courses and credentials offered by different providers. Quantum Valley Lower Saxony in Germany brings together universities, vocational education and training providers, research organisations, employers and government around the development and application of quantum technologies. It can relate emerging competence needs to courses, credentials and occupational roles and support dialogue among the organisations responsible for education, research and employment (QVLS, n.d.^[93]). The number of partners and activities demonstrates regional engagement but does not establish whether learners can move through coherent and recognised routes. Monitoring should examine whether the initiative improves access to suitable provision, connects learners with recognised education and helps employers interpret the competence developed. Responsibilities for information, referral and evaluation should be clear, while recognised education providers retain responsibility for curriculum, assessment, academic standards and qualifications.

Together, the examples show that emerging fields require differentiated provision rather than a single route. Competence frameworks can make different areas and levels of competence visible, short credit-bearing provision can address defined learning needs, and regional intermediaries can connect dispersed

provision with educational and occupational purposes. These elements form coherent skills-renewal routes only when prerequisites, learning outcomes, assessment, recognition and subsequent opportunities are clear.

2. Enabling shorter learning to accumulate towards larger qualifications

Short and modular provision can make higher education more accessible. Where they are intended to contribute to a larger qualification, learners need clear information about quality, sequencing, recognition and progression. The examples below illustrate the institutional and system arrangements required.

Portugal's Adults Impulse (*Impulso Adultos*) initiative uses public investment to expand institutional capacity for adult learning. Funded through the national Recovery and Resilience Plan, it supports higher education institutions in developing short courses, micro-credentials, postgraduate provision and flexible learning for adults. Institutions can combine curriculum development with scholarships and delivery arrangements intended to make participation more compatible with employment and other responsibilities (DGES, n.d.^[94]; Caetano, Casanova and Moreira, 2023^[95]).

The initiative can expand provision for learners unable to follow conventional full-time routes and strengthen institutional capacity for flexible delivery, adult guidance, recognition of previous learning and employer engagement. Scholarships can reduce participation costs, although scheduling, employer support, travel and access to laboratories or specialist facilities may remain barriers. The number of courses and participants demonstrates implementation but does not show whether components form coherent routes or contribute to recognised qualifications. Monitoring should therefore examine who participates and completes, how learning is recognised, whether participants progress to further study or apply their competence at work, and how outcomes differ according to previous education, employment, location and personal circumstances. Public investment in course development should be accompanied by resources for recognition, guidance and longer-term monitoring.

Ireland's Human Capital Initiative *MicroCreds* project provides shared national infrastructure for short, quality-assured higher education provision. Supported by EUR 12.3 million and involving seven universities, it has developed a national framework for micro-credentials, common standards for credit, size, accreditation and quality assurance, employer engagement, and a portal through which learners can identify courses (HEA, n.d.^[96]; IUA, 2026^[97]).

The common framework and portal make provision more visible and comparable across participating universities, while academic credit and university quality assurance certify assessed higher education learning. Employer engagement can help identify needs ranging from focused updating to deeper specialisation or movement into an adjacent field. These arrangements do not, however, automatically create routes towards larger qualifications. Institutions still need to determine which micro-credentials contribute to particular awards, how they should be sequenced, which admission requirements apply and what further learning is required. Monitoring should follow whether learners combine micro-credentials, receive recognition for the credit earned, progress to further learning or larger qualifications, and use the competence developed in employment. Compatible learner records can support this analysis, subject to appropriate safeguards and without adding unnecessary administrative barriers.

Together, the examples illustrate complementary elements of modular higher education. *Impulso Adultos* invests in institutional capacity to provide adult-focused learning, while *MicroCreds* Ireland establishes shared standards, information and credit arrangements across participating universities. In both cases, the central policy question is whether adults can identify components suited to their objectives, understand how they connect, obtain predictable recognition and progress without unnecessary repetition.

Lessons across the approaches

Coherent skills-renewal routes need to reflect learners' existing competence and intended destinations. Updating existing advanced STEM skills, developing deeper specialisation, moving into an adjacent field and making a more substantial occupational change require learning of different depth, breadth and duration. This differentiation is important because, as Chapter 1 shows, participation data do not reveal what learners sought to achieve or whether the provision corresponded to their starting points and objectives.

Competence frameworks can make the knowledge and skills required in emerging fields more visible, but they create usable routes only when translated into clear entry requirements, learning outcomes, assessment and recognised provision. Recognition, diagnostic assessment and bridge provision can then connect previous learning with remaining requirements and reduce unnecessary repetition without weakening essential foundations.

Short courses and micro-credentials can support focused updating or contribute to a larger qualification. Learners need clear information about their level, content, prerequisites, assessment, recognition and purpose. Academic credit indicates the level and volume of learning but does not by itself create a route to a qualification. Accumulation requires deliberate sequencing, predictable recognition, integrative learning and a defined destination award.

Flexible formats can help adults combine learning with employment, care and other responsibilities, but do not necessarily make provision usable. Fees, forgone earnings, schedules, travel, care responsibilities and access to educators, laboratories, equipment, collaborative learning and feedback remain important. Employers can contribute finance, paid learning time and opportunities to apply renewed competence, but learning should remain portable and useful beyond one organisation.

National and regional initiatives can support shared information, quality standards and co-operation among higher education institutions, vocational providers, employers, research organisations and professional bodies. Intermediaries can help learners and employers interpret available options, while recognised education institutions remain responsible for admission, curriculum, assessment, recognition and qualification standards.

Monitoring should distinguish among focused updating, deeper specialisation, movement into an adjacent field and more substantial occupational change. It should examine learners' starting points and objectives, recognition of previous learning, progression across components, completion and subsequent use of renewed competence. This can help determine whether provision addresses the fragmented and difficult-to-use skills-renewal routes identified in Chapter 1 or merely increases the number of individual courses available.

Policy Priority 3. Renew STEM programmes

Programme renewal can become a policy priority when STEM programmes no longer develop the knowledge and skills needed for further education or work. Programme renewal may update disciplinary content and methods, strengthen connections among courses and competence dimensions, improve practical learning, clarify what a qualification certifies, and remove outdated content or unnecessary repetition. This requires a programme-level process covering objectives, content, sequencing, teaching, assessment and learning environments rather than isolated additions to the curriculum. Disciplinary and methodological foundations remain essential. Programmes focused too narrowly on current technologies or vacancies may prepare learners to use particular tools without developing the understanding needed to evaluate evidence, apply knowledge responsibly and adapt to future change.

Collaboration with employers, research organisations, professional bodies and other users of advanced STEM skills can inform programme renewal and contribute to its delivery. These partners in design and implementation may identify changes in knowledge, technology and professional practice; contribute authentic problems, specialist expertise and facilities; and support projects, placements, traineeships and other forms of work-based learning. However, higher education institutions retain responsibility for programme coherence, assessment, qualification standards and ensuring that the learning remains useful across technologies, organisations and professional settings.

Public policy has a role where funding, regulation or organisational structures limit institutions' capacity for programme renewal, or where collaboration and shared provision produce benefits beyond an individual institution. Public authorities can support programme leadership, staff development, infrastructure, curriculum development, collaboration and evaluation. Higher education institutions remain responsible for programme design, teaching, assessment and academic standards.

This priority comprises two sub-priorities:

1. renew STEM programmes to develop and connect the four competence dimensions
2. develop STEAM programmes by integrating STEM and non-STEM disciplines

Renewal requires sustained institutional capacity. Programme leaders need recognised time, authority, evidence and educational-development support. Institutions need qualified academic and technical staff, suitable infrastructure and resources for co-ordination. Proposed additions should be considered alongside existing requirements and learner workload. Shared provision also requires clear responsibilities for admission, teaching, assessment, learner support, recognition and quality assurance.

3.1 Renew STEM programmes to develop and connect the four competence dimensions

Policy rationale, intended outcomes and potential risks

Changes in knowledge, technology, methods and professional practice can alter the advanced STEM skills required across fields and applications. Emerging fields may also combine knowledge and methods that do not fit established disciplinary or departmental structures. Programmes may therefore need to develop different combinations of disciplinary, interdisciplinary, transversal and professional competence while preserving appropriate disciplinary foundations. Programme renewal can help learners contribute to changing fields and adapt as their methods and applications develop.

Disciplinary competence remains the foundation of advanced STEM education. Learners need sufficient depth to understand the concepts, methods, representations and standards of evidence through which knowledge is produced and evaluated. This enables them to assess the quality and limitations of methods, interpret uncertainty and continue learning as tools and technologies change. Specialised and applied content should therefore build on appropriate disciplinary and methodological grounding rather than replace them.

Interdisciplinary, transversal and professional competence dimensions of advanced STEM skills extend disciplinary competence in different ways. Interdisciplinary competence enables learners to connect knowledge and methods from different fields around a shared question, design task or professional problem. It requires them to understand what each field contributes, how it frames and investigates problems, and how different contributions can be combined. Transversal competence supports communication, collaboration, critical thinking, problem-solving and continued learning, but should be developed through substantive STEM learning rather than generic activities at the margins of a programme. Professional competence concerns the responsible application of advanced STEM skills in occupational, organisational, ethical and regulatory settings. Projects, laboratories, research, simulations

and work-based learning can develop these dimensions where learners undertake substantive responsibilities, receive suitable supervision and connect experience with academic learning.

Programmes do not need to give equal weight to all four dimensions of competence. The appropriate combination depends on the field, qualification level and intended educational or occupational destination. A research-oriented master's programme may emphasise disciplinary and methodological depth and independent research. An applied engineering programme may combine strong foundations with substantial professional practice, while an emerging interdisciplinary programme may require depth in one or more contributing fields together with explicit integration. Each programme should therefore make its competence profile visible and reflect it consistently in curriculum, teaching and assessment.

Curriculum and assessment mapping can show where the four dimensions are introduced, developed, connected and assessed. It can reveal gaps, unnecessary repetition and points at which learners are expected to integrate knowledge without the required foundations. It can also identify whether access to practical, collaborative or professional learning depends on optional or informally allocated opportunities. Assessment should make individual learning visible, including within group projects, and should not allow collective outputs to conceal unequal access to technical, analytical or leadership responsibilities.

Collaboration can extend the expertise, infrastructure and learning environments available to a programme. Institutions may share courses, laboratories, educators and specialist facilities, while employers, research organisations and professional bodies may contribute through curriculum consultation, authentic projects, specialist teaching, placements and work-based learning. External contributions should have clear learning outcomes, suitable supervision and aligned assessment. They should also develop competence that remains useful beyond a particular organisation or technology.

Shared provision requires coherent programme leadership and clear responsibilities. Learners need aligned calendars, compatible credit and assessment, clear points of contact and access to support. Participating organisations need agreed responsibilities for learning outcomes, teaching, supervision, assessment, quality assurance and recognition. Collaboration should complement academic expertise rather than fragment responsibility for the programme.

Public policy has a role where funding, organisational arrangements or fragmented responsibilities limit institutions' capacity for sustained programme renewal. It should not prescribe a uniform curriculum or equate responsiveness with direct alignment to reported employer demand. The intended outcome is STEM provision with an explicit competence profile, a coherent curriculum and credible assessment. Learners should develop appropriate disciplinary depth together with the interdisciplinary, transversal and professional competence required by the programme's purpose. Qualifications should communicate this learning clearly and support progression, responsible professional practice and later skills renewal.

The main potential risks are that programme renewal adds content and activities without improving programme coherence or the competence learners develop. New content may increase workload or fragment learning if obsolete or duplicative requirements are not removed. Interdisciplinary activities may bring fields together without developing or assessing integration, while transversal and professional competence may be stated as outcomes without being developed through substantive learning. Shared provision may depend on temporary funding or individual relationships, and employer participation may narrow learning around current tools or organisational requirements. Mobility requirements, unpaid participation and informal selection may also create unequal access to parts of the renewed programme.

Monitoring should therefore examine whether learners develop and demonstrate the intended competence, not only whether curricula refer to the four dimensions or introduce new courses and partnerships. Evidence may include curriculum and assessment mapping, learner achievement, progression and completion, equitable access to substantive practical and collaborative learning, and how learners, receiving institutions and employers interpret programme outcomes. Monitoring should also assess whether renewal preserves disciplinary and methodological foundations, connects curriculum,

teaching and assessment, and is supported by sufficient staff, infrastructure, leadership and sustained funding. This can help determine whether renewal addresses the gaps between programme labels, qualifications and the advanced STEM skills developed and used in practice discussed in Chapter 1.

Examples of interventions

The examples illustrate four connected approaches: establishing common foundations for interdisciplinary STEM learning; defining competence in an emerging interdisciplinary field; and building programmes around a common technical and methodological core; and co-designing and delivering programmes with employers and other external partners.

The examples show that interdisciplinary STEM education requires both disciplinary depth and explicit integration. Common content or participation in courses from several fields does not by itself develop interdisciplinary competence. Learners need opportunities to connect concepts, methods and evidence around shared problems and to demonstrate both their disciplinary learning and their capacity to integrate it.

Table 2.8. Selected interventions supporting interdisciplinary STEM programmes

Approach	Example	Principal policy contribution
1. Establishing common foundations for interdisciplinary STEM learning	Mathematics, Data Science and AI Education Programme Recognition System, Japan	Establish common expectations for mathematics, data science and AI learning while enabling institutions to adapt provision to disciplinary contexts and qualification levels.
2. Defining competence in an emerging interdisciplinary STEM field	European Competence Framework for Quantum Technologies; Certification Scheme for Quantum Technology Proficiency	Describe the disciplinary and interdisciplinary competence required across quantum-technology profiles and provide a reference for curriculum and assessment.
3. Building programmes around a common technical and methodological core	Interdisciplinary Computing, IT:U Austria; European Universities alliances; Digitally Enhanced Quantum Technology Master	Combine foundations, specialisation, research and application while pooling expertise and infrastructure across programmes and institutions.
4. Co-designing and delivering programmes with employers and other external partners	Youth Impulse STEAM, Portugal	Use structured partnerships among higher education institutions, employers, research organisations and public authorities to inform programme design and contribute projects, professional expertise, workplace learning and infrastructure.

1. Establishing common foundations for interdisciplinary STEM learning

Interdisciplinary STEM learning can be difficult when learners enter with different disciplinary backgrounds or lack knowledge and methods required across the participating fields. Common foundations in mathematics, data science and artificial intelligence can provide a shared basis for communication, analysis and problem-solving, help learners understand concepts and methods assumed in later courses, and reduce gaps or unnecessary repetition across programmes. However, common foundations do not develop interdisciplinary competence on their own. Learners need to connect them with the concepts, methods, evidence and applications of the fields in which they are used. Institutions should therefore integrate common foundations with disciplinary teaching, practical learning and assessment rather than provide them as detached or generic content.

Japan's Mathematics, Data Science and AI Education Programme Recognition System illustrates this approach (Takahashi et al., 2026^[98]). Established by the Ministry of Education, Culture, Sports, Science and Technology, it responds to uneven provision of mathematics, data science and AI across higher education. It provides a national framework and model curriculum while allowing universities, junior colleges and colleges of technology to adapt implementation to their missions, disciplines and learner populations.

The framework distinguishes a literacy level providing common foundations across fields from an applied-basic level in which learners apply mathematics, data science and AI in particular disciplinary and professional contexts. It also relates these levels to advanced specialist development. The literacy curriculum covers data handling and interpretation, statistical reasoning, AI concepts and applications, and ethical, legal and social considerations (Shimbaru, 2025^[99]).

Implementation requires staff expertise, curriculum-development capacity and arrangements for connecting common content with disciplinary programmes. National expectations can reduce fragmented provision, while institutional flexibility allows adaptation to different disciplines and learners. This flexibility may nevertheless produce variation in the depth, assessment and disciplinary integration of provision. The national framework, recognition arrangements and supporting consortium demonstrate system-level reform, but do not establish whether learners develop and apply the intended competence.

Monitoring should therefore examine participation, assessed learning, progression between levels and the application of mathematics, data science and AI in subsequent disciplinary study. It should also assess whether common foundations are connected with disciplinary teaching, laboratories, projects and assessment and support credit and progression. The relevant question is not only whether programmes include common content, but whether learners develop disciplinary, interdisciplinary, transversal and professional competence in connected ways.

2. Defining competence in an emerging interdisciplinary STEM field

Emerging STEM fields often combine knowledge and methods from established disciplines but lack a shared language for describing the competence required. Competence frameworks can support programme renewal by identifying relevant domains and proficiency levels and making differences among educational and occupational profiles more visible. They do not, however, determine how disciplinary, interdisciplinary, transversal and professional competence should be developed and assessed within a coherent programme.

The European Competence Framework for Quantum Technologies, discussed under Policy Priority 2.3, distinguishes competence domains, proficiency levels and qualification profiles across physics, mathematics, computing, engineering and application-related fields. Institutions can use these distinctions to define programme outcomes, map disciplinary and interdisciplinary learning and explain what programmes develop (European Commission, 2025^[90]). They still need to translate the profiles into entry requirements, curriculum content, sequencing, teaching, practical experience and assessment. They must also determine how learners develop disciplinary depth and integrate contributions from the participating fields. Treating a competence profile as a checklist of topics would not produce a coherent programme.

The Certification Scheme for Quantum Technology Proficiency adds an assessment-oriented component. It defines six levels across three proficiency areas, provides sample tasks for introductory levels and identifies forms of work, including theses, technical-development projects and strategic analyses, through which more advanced competence could be demonstrated (Greiner, Hilfert-Rüppell and Müller, 2025^[100]). This can help higher education institutions and continuing-education providers connect curricula and assessment with clearer expectations. However, the scheme does not replace institutional assessment or qualification-awarding authority, and evidence of its adoption remains limited. It should therefore be understood as a resource for curriculum and assessment mapping rather than a certification system operating at scale.

Together, the framework and proficiency scheme show why the contributing disciplines should remain visible within an interdisciplinary programme. Learners need to understand which concepts and methods come from physics, mathematics, computing and engineering, how these contributions connect and how their quality and limitations can be assessed. Interdisciplinary competence requires this integration, not simply exposure to several fields.

3. Building programmes around a common technical and methodological core

Interdisciplinary programmes need to combine appropriate disciplinary depth with structured opportunities to integrate concepts, methods and evidence across fields. This requires more than assembling courses from different departments. A common technical or methodological core can provide coherence, while specialisations, projects and research enable learners to apply and extend that core in different domains.

The following examples illustrate three organisational forms: a purpose-designed programme within one institution, cross-border provision through university alliances, and a specialised network through which learners access shared provision while remaining enrolled in a home qualification.

The Interdisciplinary Computing master's programme at IT:U Austria illustrates programme design within one institution. Launched in 2025/26, it connects computing with health and life sciences, environmental and social systems, digital humanities, interaction design and industry. Learners from different disciplinary backgrounds follow a curriculum combining common foundations, laboratory experience, research training, specialist routes and increasingly independent project work (IT:U, n.d.^[101]; IT:U, n.d.^[102]; BMFWF, n.d.^[103]). Computing provides the technical and methodological core, while the application domains enable learners to connect computational methods with the concepts, evidence and constraints of other fields. Laboratories, projects and the thesis provide opportunities to demonstrate this integration and consider its social, ethical and organisational implications.

A common core can ensure that interdisciplinarity is not a collection of unrelated electives. Learners entering with different backgrounds may also need differentiated preparation to access the technical core and application domains without unnecessary repetition. As the programme and university are recent, evidence on progression, completion and graduate outcomes is not yet available. Monitoring should examine achievement in computing foundations, integration of domain knowledge in projects and theses, progression and completion, and differences according to learners' previous disciplines. Implementation will also require sustained programme leadership, educational-development expertise and laboratory and technical capacity.

Where expertise and infrastructure are distributed across institutions, cross-border collaboration can extend the learning available to students. By 2025, European Universities alliances involved more than 570 higher education institutions across 35 countries and had developed more than 600 joint educational offers, including degrees, courses and micro-credentials (European Commission, 2025^[104]; European Commission, 2025^[105]; Binder and Bol, 2025^[106]). Collaboration with research organisations, employers, community organisations and public bodies can also provide settings for learning about digitalisation, sustainability and other societal challenges.

The alliances can combine expertise, teaching capacity and infrastructure that individual institutions may be unable to sustain. However, differences in regulation, quality assurance, funding, academic calendars and recognition can make joint provision complex and costly. Participating institutions therefore need clear responsibilities for admission, curriculum, teaching, assessment, learner support, quality assurance and recognition (European Parliamentary Research Service, 2023^[107]; ENQA, 2025^[108]). The number of institutions and joint offers demonstrates the scale of collaboration but not whether learners can follow coherent and sustainable routes. Monitoring should examine the availability, recognition and educational coherence of joint provision and whether financial circumstances, disability, caring responsibilities or mobility requirements affect access.

The Digitally Enhanced Quantum Technology Master, or DigiQ, provides a more specialised network model. It brings together 24 organisations from 10 countries and supports 16 quantum-technology master's programmes through shared courses, digital resources, networks, mobility, research projects and internships (DigiQ, n.d.^[109]). Learners remain enrolled in a master's programme at a participating university and use the network's provision to develop an additional quantum-technology profile. Those who complete 30 ECTS of eligible courses and participate for one year in a DigiQ network can receive supplementary

certification. Courses are mapped against the European Competence Framework for Quantum Technologies, while each home institution determines how external courses, projects, mobility and thesis work contribute to its degree (Goorney, Sarantinou and Sherson, 2024^[110]).

This model can widen access to specialist provision while preserving the home institution's responsibility for the principal qualification. Its value depends on timely recognition of external learning, compatible calendars and clear information about how shared components contribute to the home programme. Monitoring should examine recognition and completion, access to shared courses and facilities, participation costs, and how employers and receiving institutions interpret the supplementary certification.

Together, the examples show how a common technical or methodological core can provide coherence across different applications and specialisations. Collaborative provision can widen access to expertise and infrastructure, but it also requires programme co-ordination, recognition and learner support. Monitoring should examine whether learners develop and demonstrate disciplinary depth and integration across fields, not only whether programmes are described as interdisciplinary. Where learning is delivered by other institutions or partners, the institution awarding the principal qualification should ensure that it contributes coherently to the programme's outcomes, curriculum and assessment.

4. Co-designing and delivering programmes with employers and other external partners

Employers, research organisations, professional bodies and public authorities can all contribute to programme renewal by helping higher education institutions identify changes in professional practice, technology and the settings in which advanced STEM skills are applied. As discussed in Chapter 1 in the sections on the transition to employment and the effective use of advanced STEM skills, employer-reported needs do not by themselves establish which competence is lacking or how programmes should respond. External partners can nevertheless contribute occupational knowledge, authentic problems, specialist teaching, workplace learning and access to professional expertise, facilities and equipment.

Their involvement may extend from curriculum consultation to the joint development of study plans, projects and practical learning. External contributions should support coherent programme outcomes rather than narrow learning around the immediate requirements of individual organisations. Higher education institutions remain responsible for programme design, assessment, qualification standards and the portability of learning.

Portugal's Youth Impulse STEAM programme illustrates how public funding can make structured external collaboration part of higher education programme development and delivery. Funded through Portugal's Recovery and Resilience Plan for 2021-26, it supported public and private higher education institutions working individually or in consortia with employers, research organisations and national, regional and local authorities. It was implemented alongside Impulso Adultos, discussed under Policy Priority 2.3. Together, projects funded through the two programmes involved more than 2 000 external organisations (DGES, 2022^[111]).

Youth Impulse STEAM combined expanded provision in science, technology, engineering, arts and mathematics with infrastructure investment and different forms of co-design and co-delivery. Employers and regional partners helped identify competence needs, design courses, contribute authentic projects and support workplace learning. Projects addressed fields including digital technologies, engineering and manufacturing, renewable energy, decarbonisation, the circular economy and sustainable production. Some developed short-cycle programmes with industry, while others involved employers in bachelor's, postgraduate and shorter provision or practice-based learning environments (DGES, 2022^[111]).

Interim evaluations indicate substantial expansion in provision, infrastructure and collaboration, as well as changes in curricula and teaching practices. They focus primarily on implementation, financial execution and progress against contracted targets and provide less evidence on effects on learning, completion, employment or skills use (DGES, 2024^[112]; DGES, 2025^[113]). Further evaluation should examine whether

external collaboration changes what learners develop and demonstrate, whether all learners gain access to substantive professional learning, and whether the resulting advanced STEM skills are used effectively after graduation. These questions connect the programme-renewal and career-entry bottlenecks discussed in Chapter 1.

Lessons across the approaches

Programme renewal begins with a clear definition of the competence learners should develop. The balance among disciplinary, interdisciplinary, transversal and professional competence varies by field, qualification level and programme purpose. As discussed in Chapter 1, programme titles and qualification categories do not by themselves show the depth developed, how knowledge and methods are integrated or which educational and professional routes a programme supports. Curriculum, teaching and assessment therefore need to make the intended competence profile visible.

Disciplinary and methodological foundations enable learners to understand concepts, methods, evidence and uncertainty and to adapt as technologies change. Interdisciplinary competence requires structured opportunities to connect contributions from different fields around shared questions or applications. Common foundations and competence frameworks can support this process, but do not create integration by themselves. Programmes need to show how learners apply and connect the relevant knowledge and methods.

A common technical or methodological core can give an interdisciplinary programme coherence, while specialisations, projects and research connect it with different applications. Curriculum and assessment mapping can show where the four competence dimensions are introduced, developed, connected and assessed. It can also identify missing foundations, unnecessary repetition and unequal access to practical, collaborative or professional learning. Assessment should make individual competence and contribution visible, including within group projects.

Employers, research organisations, professional bodies and public authorities can contribute authentic problems, specialist expertise, facilities, projects and workplace learning. Their involvement can connect disciplinary foundations with professional application while higher education institutions remain responsible for programme coherence, assessment and qualification standards. Agreements should clarify learning outcomes, partner roles, supervision, resources, recognition and quality assurance.

Collaboration across institutions can widen access to specialist educators, courses, laboratories and research environments. Coherent shared provision requires compatible calendars and credit, predictable recognition, aligned assessment and effective learner support. Mobility requirements, different institutional rules and temporary funding may nevertheless create barriers. The institution awarding the qualification remains responsible for ensuring that externally delivered learning contributes coherently to the programme.

Monitoring should examine whether renewed programmes develop and connect the intended four dimensions of competence, preserve appropriate disciplinary depth and provide equitable access to substantive practical and professional learning. It should also assess whether programme renewal improves progression, preparation for research and employment, the effective use of advanced STEM skills and foundations for later skills renewal. This connects programme-level reform with the bottlenecks identified in Chapter 1 without assuming that curriculum change alone can resolve them.

3.2 Develop STEAM programmes by integrating STEM and non-STEM disciplines

Policy rationale, intended outcomes and potential risks

Technologies are developed, adopted and used within social, organisational, cultural, economic and regulatory contexts. Scientific and technical knowledge expands what people and organisations can do, but does not determine which purposes should be pursued, whose needs should be prioritised or which forms of use are responsible. Addressing these questions may require interpretive, creative, behavioural, ethical and critical perspectives alongside scientific and technical competence.

STEAM brings STEM and non-STEM disciplines together in a shared process of enquiry. It should preserve appropriate disciplinary competence while enabling learners to integrate concepts, methods, evidence and perspectives across fields. It may also develop transversal and professional competence through collaboration and the responsible application of knowledge. STEAM is one possible form of integration and is not required for every STEM programme.

Stand-alone courses in ethics, communication, design or entrepreneurship can broaden STEM education, but deeper integration requires non-STEM contributions to influence how technological problems are defined, addressed and evaluated. These contributions may shape whose needs and experiences are considered, what counts as relevant evidence, which technical and non-technical options are examined, and how benefits, risks and consequences are assessed. Scientific and technical knowledge should, in turn, inform enquiry and practice in the contributing non-STEM fields. Three connected constraints can weaken integration.

First, programmes may reproduce a hierarchy in which STEM disciplines define the problem and solution while non-STEM fields contribute mainly to communication, commercialisation or public acceptance. Design, behavioural, legal, social, cultural and ethical knowledge should influence technical decisions before the main requirements and solutions are fixed. Integration should also remain reciprocal: non-STEM contributions can shape purposes, requirements and evaluation, while STEM expertise establishes feasibility, reliability, security and performance.

Second, programmes may include several disciplinary contributions without connecting them in practice. Learners may develop a technical system, conduct user research and prepare a legal or ethical analysis as separate tasks. Integration requires these contributions to influence one another. Projects and assessment should therefore show how user research, design, legal analysis or other non-STEM evidence changed the problem definition, data, system requirements, alternatives considered or evaluation of the result.

While learners do not need the same depth of disciplinary competence in every participating field, they should nevertheless understand the contributions and limitations of the relevant disciplines and be able to explain how these influenced the final approach. Hence, assessment need to examine both the quality of the disciplinary contributions and their integration (Tomlinson and Anderson, 2020^[114]).

Third, organisational arrangements may prevent participating fields from contributing as equal academic partners. A department providing a guest lecture or elective may have little influence over programme outcomes, project design, supervision or assessment. Governance should therefore assign substantive responsibilities for curriculum, teaching, supervision and assessment across participating fields, including where provision extends across several institutions.

External partners can contribute authentic problems, operational knowledge and perspectives on how technologies interact with users, regulation and organisations. Their participation should shape the enquiry rather than validate a solution already selected. Higher education institutions should retain responsibility for academic independence, learning outcomes, assessment and learner protection. Where community or

user knowledge is central, project design should provide for appropriate participation, attribution and reciprocal benefit.

Public policy has a role where disciplinary structures, funding models, workload arrangements or quality-assurance requirements make such integration difficult to establish or sustain. Public authorities can support curriculum co-design, recognised staff time, programme leadership, shared infrastructure, collaborative teaching and suitable quality-assurance and recognition arrangements. They should enable different forms of integration without requiring every STEM programme to adopt a STEAM approach. Higher education institutions remain responsible for curriculum, assessment, academic independence and qualification standards.

The intended outcome of policy intervention is for learners to develop strong disciplinary competence in their principal field and interdisciplinary competence that enables them to integrate knowledge, methods, evidence and perspectives from STEM and non-STEM disciplines. They should also develop the transversal and professional competence needed to communicate and collaborate across fields and apply their advanced STEM skills with ethical judgement, regulatory awareness and an understanding of organisational and social contexts. Programme descriptions and qualification profiles should make the disciplinary foundations, form of integration and competence assessed clear. This responds to the limitation identified in Chapter 1 that programme labels alone do not reveal what competence learners develop or how different forms of knowledge are connected.

A potential unintended consequence is that measures intended to develop STEAM programmes bring disciplines together without preserving disciplinary depth or enabling learners to integrate their contributions. Non-STEM content may remain optional or be introduced only after the main technical decisions have been made. Conversely, broad engagement with societal questions may displace essential scientific, technical or methodological foundations. Learners may be expected to connect disciplines without suitable teaching, while group projects may conceal gaps in individual competence or unequal access to substantive responsibilities. External partners may prioritise immediate outputs over learning, and cross-departmental provision may remain dependent on temporary funding or unrecognised staff effort.

Monitoring should therefore examine whether integration occurs in curriculum, teaching and assessment and whether it influences the programme's shared questions and technical decisions. Relevant evidence includes disciplinary achievement; learners' ability to connect concepts, methods, evidence and perspectives; the influence of non-STEM contributions on problem definition, requirements and evaluation; and the distribution of substantive responsibilities in collaborative work. Monitoring should also examine individual learning within group projects, progression and completion, the interpretation of qualifications, the influence of participating disciplines on programme design and assessment, and the sustainability of collaborative provision. This can help determine whether programmes preserve suitable disciplinary foundations and develop the connected disciplinary, interdisciplinary, transversal and professional competence discussed in Chapter 1.

Examples of interventions

The examples illustrate three approaches: integrating futures literacy into higher education curricula; integrating computing, design and behavioural science through human-computer interaction; and pooling complementary expertise through European joint provision. Across the three approaches, the central question is whether non-STEM knowledge influences technological problem definition, requirements, development and evaluation rather than remaining an elective, contextual or downstream addition.

Table 2.9. Selected interventions to integrate STEM and non-STEM disciplines

Approach	Example	Principal policy contribution
1. Integrating futures literacy, understood as the ability to anticipate, critically examine and help shape possible futures, into higher education curricula	FuturesComp, Austria	Provide a shared reference for integrating anticipation, critical reflection, values and action concerning alternative futures into higher education curricula and transdisciplinary learning.
2. Integrating computing, design and behavioural science through human-computer interaction	Master of Human-Computer Interaction, Carnegie Mellon University, United States; Human-Computer Interaction MSc, University College London, United Kingdom	Create a common field in which technical, design and behavioural-science knowledge jointly influence problem definition, user research, requirements, prototyping and evaluation.
3. Pooling complementary expertise through European joint provision	Human-Computer Interaction and Design with Extended Reality, EIT Digital Master School	Pool technical, behavioural, design and innovation expertise through a common programme structure, mobility, shared quality arrangements and dedicated co-ordination across European universities.

1. Integrating futures literacy, understood as the ability to anticipate, critically examine and help shape possible futures, into higher education curricula

Austria has developed *FuturesComp*, a competence framework designed to support the integration of futures literacy into higher education curricula, modules and courses (Bierwisch, 2026^[115]). Commissioned by the Austrian Federal Ministry for Women, Science and Research, it was developed by an interdisciplinary team from the UNESCO Chair in Futures Capability for Innovation and Entrepreneurship at MCI Innsbruck and the UNESCO Chair in Learning and Teaching Futures Literacy in the Anthropocene at the University College of Teacher Education Lower Austria. Its development drew on literature reviews, interviews with international experts and focus-group workshops (Bierwisch, 2026^[115]).

FuturesComp treats the future not as a predetermined outcome but as a range of possibilities that learners can anticipate, critically examine and help shape. It identifies five interrelated competence areas: exploring possible futures, assuming shared responsibility for them, shaping them, developing oneself in relation to them and participating in them. These areas are specified through cognitive, affective, imaginative and action-oriented dimensions, learning objectives and examples of teaching practice. Higher education institutions can use the framework within existing curricula or to develop transdisciplinary formats connecting higher education, society and professional practice (Bierwisch, 2026^[115]); (BMFWF, 2026^[116]).

For STEM programmes, the framework can encourage learners to examine how scientific and technological developments interact with uncertainty, societal values, competing objectives and alternative development paths. This responds to the Chapter 1 discussion of responsible application by helping learners consider not only what is scientifically or technically possible, but also which purposes and consequences should inform decisions. Futures literacy can thereby contribute to interdisciplinary, transversal and professional competence alongside disciplinary competence. Monitoring should examine whether learners become better able to question assumptions, compare possible developments and integrate scientific, technical, societal and ethical evidence.

2. Integrating computing, design and behavioural science through human-computer interaction

Human-computer interaction provides a focused example of integration between STEM and non-STEM disciplines. Designing interactive technologies requires computing and engineering knowledge, design methods for developing and testing alternatives, and behavioural and social-science methods for understanding users and contexts. Technical feasibility, human behaviour, accessibility and design quality therefore need to inform the same development process. Integration occurs when behavioural research and design influence problem definition, whose needs and experiences are considered, what evidence is

collected, how system requirements are formulated and which alternatives are examined. Computing and engineering knowledge, in turn, establish whether proposed solutions are feasible, reliable, secure and capable of meeting those requirements.

Carnegie Mellon University's Master of Human-Computer Interaction provides a professionally oriented model. The three-semester programme brings together learners and educators from computer science, design, cognitive psychology, behavioural science, business and related fields. Its required curriculum covers user-centred research and evaluation, interaction design, programming, communication and collaboration, followed by a seven-month capstone project undertaken by interdisciplinary teams for an external partner (Carnegie Mellon University, n.d.^[117]).

The capstone provides a shared setting in which the participating disciplines can influence connected decisions. Teams define the project scope, conduct user and contextual research, generate and assess design alternatives, and develop and test an interactive prototype through several iterations (Carnegie Mellon University, n.d.^[118]). Integration may become visible through changes to the problem definition, data collection, system requirements, technical architecture, interface, evaluation criteria or intended use. External partners can contribute professional problems, organisational constraints, existing technologies and access to relevant users or operating environments. Faculty mentors nevertheless need to ensure that sponsor expectations, delivery timelines and product requirements do not displace disciplinary learning or wider social and ethical analysis. Programmes also need alternatives where access to external data, users, facilities or partners becomes unavailable.

University College London's Human-Computer Interaction MSc provides a complementary model combining engineering, behavioural sciences and design. Learners examine the physical, cognitive, social and affective dimensions of interaction and develop competence in analysing user performance, preferences and experience. The programme admits applicants from computer science, psychology, ergonomics and related fields and combines conceptual study, practical activity, evaluation of interactive systems, prototype development and an individual research project (UCL, n.d.^[119]). The individual project provides an opportunity to connect technical, behavioural and design knowledge around a common object of enquiry while making each learner's reasoning visible. It demonstrates interdisciplinary learning when learners can explain how concepts, methods or evidence from one field influenced decisions in another.

Together, the programmes illustrate how the four competence dimensions can be connected. Computing, behavioural research and design contribute disciplinary competence, while integrating their concepts, methods and evidence develops interdisciplinary competence. Communication, teamwork, reflection and the justification of decisions support transversal competence. Authentic projects, external engagement and attention to users and organisational contexts can strengthen professional competence.

The programmes nevertheless need to balance interdisciplinary breadth with disciplinary depth. Learners entering from computing, psychology, design and related fields will not have the same previous knowledge and do not need equal depth in every participating field. Programmes should define the competence expected in each learner's principal field and the understanding needed to interpret and use contributions from other fields. Differentiated preparation may be required where previous backgrounds vary substantially.

Research on human-computer interaction education supports experiential approaches, including applied projects, placements and challenge-based learning. Reported outcomes include stronger technical knowledge, application of theory to practice, transversal competence, awareness of user diversity and preparation for employment. However, the evidence is heterogeneous and provides limited direct measurement of interdisciplinary competence (Kang, Roestel and Girouard, 2022^[120]; Sung and Han, 2025^[121]; Fan et al., 2025^[122]).

Assessment therefore needs to distinguish a successful collective output from each learner's competence. A team may produce an effective prototype while its members remain divided into separate technical,

design and research roles. Portfolios, research protocols, technical demonstrations, records of project decisions, reflective accounts and oral defence can complement collective outputs by showing what each learner understood and contributed. Disciplinary competence should be assessed through the quality of the concepts and methods used. Interdisciplinary competence should require learners to explain how contributions from one field influenced decisions in another. Transversal competence should cover communication, reflection and adaptation across fields, while professional competence should include responsible judgement and understanding of organisational practice.

3. Pooling complementary expertise through European joint provision

The EIT Digital Master School's Human-Computer Interaction and Design with Extended Reality programme illustrates how shared provision can address constraints on the expertise and resources available within individual departments and universities. Its cross-institutional model combines complementary expertise and facilities through a common programme structure, mobility and shared quality arrangements.

The EIT Digital Master School admitted its first cohort in 2012. From the outset, it combined a technical major with an Innovation and Entrepreneurship minor, study at two European universities and the award of two university degrees together with an EIT certificate (EIT, 2011^[123]; EIT, 2015^[124]). Its current Human-Computer Interaction and Design with Extended Reality programme is a two-year, 120-ECTS route combining human-computer interaction, user-centred design and extended-reality technologies with innovation and entrepreneurship. Learners study at an entry university in the first year and an exit university in the second and receive master's degrees from both institutions and an EIT Label Certificate (EIT Digital, n.d.^[125]).

The programme connects computing and immersive technologies with knowledge of users' cognitive, aesthetic, social and sensorimotor experiences. Learners may apply this learning in fields such as healthcare, education, culture and entertainment. User-centred research and design inform technological development, while innovation and entrepreneurship address how ideas can be developed into products, services and other applications.

Participating institutions contribute complementary technical, design, behavioural and innovation expertise. For the 2026/27 academic year, entry provision is listed at Aalto University, KTH Royal Institute of Technology, the University of Twente, Universidad Politécnica de Madrid and Politecnico di Milano, while other institutions, including the University of Trento, provide further specialisation opportunities (EIT Digital, n.d.^[126]). These institutions bring together expertise in computing, engineering, interaction design, behavioural research, immersive technologies and innovation (Politecnico di Milano, n.d.^[127]; Aalto University, 2026^[128]; University of Twente, n.d.^[129]).

Shared provision can give learners access to educators, research groups, technologies and specialist facilities that may not be available at one institution. It can also give design and behavioural disciplines a more substantial role than electives or occasional guest teaching. Pooling expertise does not, however, ensure that the participating disciplines shape programme decisions or that learners integrate what they study at different institutions. Common programme outcomes, curriculum mapping and integrative assessment are needed to connect learning across the entry and exit universities.

Clear responsibilities are needed across participating institutions. Programme descriptions should explain what is common across the route and which competence reflects the specialisation of particular universities. Responsibilities for programme outcomes, curriculum design, teaching, supervision, assessment, learner support and quality assurance should be clearly allocated. Movement between institutions should not itself be treated as evidence of interdisciplinary learning.

The EIT Label provides a common framework for programme outcomes and quality assurance. Learners' formal academic qualifications are the two university degrees, while the EIT Label Certificate records

shared EIT Digital outcomes relating to innovation, entrepreneurship, learning by doing and mobility (EIT, 2021^[130]). The label can make common features of the different routes visible, but needs to be accompanied by information about the disciplinary focus and competence developed through each combination of entry and exit institutions.

External research and industry partners can contribute professional problems, specialist facilities and knowledge of how technologies are developed and used. Their involvement can strengthen professional competence where learners engage with technical, organisational, user and regulatory constraints. Participating universities should nevertheless retain responsibility for educational outcomes, assessment, academic independence and learner protection. They should also provide alternatives if access to a partner, placement, facility or data source becomes unavailable.

Shared provision requires sustained funding and organisational capacity. Programme development, mobility, common quality arrangements and co-ordination depend on recognised staff time for curriculum design, joint teaching, supervision, learner support and administration. Their longer-term sustainability depends on whether participating institutions incorporate these responsibilities into regular staffing, workloads and budgets rather than relying on temporary funding or individual staff relationships.

Physical mobility may also create barriers related to cost, housing, immigration, disability, employment and caring responsibilities. Financial assistance, accessible accommodation, compatible calendars and co-ordinated learner services may therefore be necessary. Virtual participation can widen access to some courses and collaborative work but may not replace laboratories, specialist facilities and projects requiring physical presence.

Drawing on the discussion in Chapter 1, policy monitoring should examine whether the routes offered across participating institutions form coherent programmes, whether learning is recognised predictably and whether learners integrate the technical, behavioural, design and innovation components. It should also assess progression, completion, participation costs, access to mobility and shared facilities, interpretation of the double degree and EIT Label, and the sustainability of institutional co-ordination.

Lessons across the approaches

The examples show that effective STEAM programmes organise STEM and non-STEM disciplines around shared questions and connected decisions. Design, behavioural, social, legal, ethical and cultural perspectives can shape how technological problems are defined, whose needs are considered, which alternatives are developed and how outcomes are evaluated. Scientific and technical evidence can, in turn, inform enquiry and decisions in the contributing non-STEM fields.

Frameworks such as FuturesComp can help programmes introduce systematic consideration of alternative futures, assumptions, values and uncertainty. Their contribution depends on translation into programme-specific outcomes, teaching and assessment and should be judged by whether they change how learners define problems, compare alternatives and integrate scientific, technical, societal and ethical evidence.

Learners do not need the same depth of disciplinary competence in every participating field. Programmes should define the competence expected in learners' principal fields and the understanding required to interpret and use contributions from other disciplines. Interdisciplinary and futures-oriented learning should complement rather than displace the disciplinary and methodological foundations needed to assess which possible developments are scientifically credible, technically feasible and socially consequential.

Projects and assessment should make integration visible. A collective output involving several specialist roles does not establish that each learner has developed interdisciplinary competence. Assessment should therefore examine disciplinary quality, individual learning and contribution, and how concepts, methods or evidence from different fields influenced connected decisions. This responds to the Chapter 1 distinction between programme participation and the substantive development and use of advanced STEM skills.

Cross-institutional provision can pool technical, behavioural, design and other expertise that individual institutions may lack. Effective collaboration requires common outcomes, curriculum mapping, compatible credit and calendars, integrative assessment, co-ordinated learner support and clear responsibilities for teaching, supervision, quality assurance and recognition. Joint provision can nevertheless create financial, geographical and practical barriers, while temporary funding may weaken sustainability.

Monitoring should examine whether learners develop credible disciplinary foundations and can integrate knowledge, methods, evidence and perspectives across fields. It should also assess access to substantive roles, progression and completion, interpretation of qualifications, and the sustainability of collaborative provision. This can help determine whether STEAM programmes develop the connected competence required for responsible practice, rather than merely bringing several disciplines together under a shared label.

Policy Priority 4. Improve career entry, effective use and continued development of advanced STEM skills

Advanced STEM skills contribute to innovation, productivity and economic and societal development only when individuals that possess these skills can apply them at work. This means that increasing graduate numbers will not produce the expected outcome when suitable roles are unavailable.

Hence, individuals need equitable access to substantive professional experience, reliable occupational information, professional networks and employment they can realistically pursue, why employers must be able to interpret and validate advanced STEM skills, distinguish essential entry requirements from skills that can be developed on the job, provide effective onboarding and organise work in a way that values advanced STEM skills.

Higher education has an important but bounded role in career entry and continued development of advanced STEM skills. Institutions develop and assess advanced STEM skills, communicate programme content and learning outcomes, and provide opportunities for learners to apply and demonstrate their competence. They should respond to durable changes in scientific, technological and professional requirements and prepare graduates to continue learning. Collaboration with employers, research organisations and professional bodies can inform programme planning, design and delivery by contributing knowledge of professional practice, authentic problems, specialist expertise, facilities and work-based learning opportunities. Such collaboration can strengthen the connection between higher education and employment, but it does not transfer employers' responsibilities for recruitment, onboarding, work organisation and continued development to higher education institutions. Higher education institutions cannot create demand for advanced STEM skills, determine employers' recruitment practices or ensure that employees' competence is used effectively after appointment.

Employers determine which roles are available, how entry requirements are specified, which evidence is recognised and how applicants are assessed. After recruitment, they determine whether employees receive effective onboarding, undertake substantive work, gain access to feedback and mentoring, and progress towards greater autonomy, specialist depth, professional responsibility and advancement. Public support should not transfer these ordinary employer responsibilities to higher education institutions or graduates.

Public authorities can support accessible professional experience, improve information on qualifications and employment outcomes, facilitate collaboration between higher education institutions and employers, and help organisations with limited internal capacity improve recruitment, onboarding and employee development. They can also influence employment conditions through labour-market regulation, public employment, research funding and conditions attached to publicly supported programmes. Their influence

is nevertheless limited because many decisions concerning recruitment, task allocation, management and advancement remain with individual employers.

The appropriate response therefore depends on the constraint identified. Where graduates lack a required combination of disciplinary, interdisciplinary, transversal and professional competence, higher education institutions may need to review programme design, teaching, assessment or opportunities for practical application. Where relevant advanced STEM skills are available but difficult to interpret or validate, improved information and recruitment practices may be required. Where skills are recognised but not used or developed, the response lies primarily in onboarding, management, task allocation, work organisation and advancement. Where suitable roles remain unattractive because of pay, insecurity, location or working conditions, increasing graduate supply is unlikely to resolve the problem.

Monitoring should therefore examine not only placements, recruitment and mentoring arrangements, but also access to professional experience, recruitment and onboarding practices, task complexity, autonomy, continued development, retention and the actual use of advanced STEM skills. It should distinguish outcomes that policy can influence directly from those that depend mainly on employer decisions and assess whether changes continue after public support ends.

4.1 Support employers to recognise, recruit, and use advanced STEM skills

Policy rationale, intended outcomes and potential risks

Recruitment is only the beginning of the transition into work. Graduates may have strong disciplinary and methodological foundations but still need to learn an organisation's technologies, procedures, standards and professional relationships. Effective onboarding can widen the range of suitable candidates and help new employees progress towards independent work. This organisation-specific learning is primarily the employer's responsibility, not that of higher education.

After onboarding, effective skills use depends on how work is organised. Substantive problems, suitable technologies, complementary expertise and scope for professional judgement allow employees to apply their advanced STEM skills and contribute to organisational performance. Routine or narrowly defined work may leave these skills underused. As Chapter 1 explains, indicators based on occupations or qualifications alone cannot show whether advanced STEM skills are used effectively.

Continued development can deepen specialist competence and support progression into more complex work, technical leadership or research responsibility, rather than management alone. Pay, employment security, location, working conditions and advancement arrangements influence whether employees remain in roles that use and develop their advanced STEM skills. Where recruitment or retention difficulties arise mainly from these conditions, increasing graduate supply is unlikely to resolve them.

Public policy intervention may be justified where unequal access, information and co-ordination gaps, wider benefits or limited capacity among smaller employers lead to underinvestment in the effective use of advanced STEM skills. Public authorities and intermediary organisations can support common information, paid professional experience, recruitment assistance, collaboration and employer capacity. The intended outcome is sustainable employment in which advanced STEM skills are recognised, used and continually developed. The scope of policy intervention remains limited because employers determine recruitment criteria, onboarding, task allocation, work organisation, working conditions and advancement.

A potential unintended consequence is that measures intended to improve career entry increase placements or recruitment without improving the substance of work or opportunities for continued development. Placements and supported roles may provide routine tasks, competence descriptions may not change recruitment practices, and formal mentoring may offer little meaningful guidance or feedback. Publicly supported positions may replace regular employment, while employer-linked arrangements may

become too specific to one organisation or technology, limiting the usefulness of the competence and experience developed elsewhere.

Examples of interventions

The examples illustrate four connected approaches through which employers, higher education institutions, public authorities and intermediary organisations can support career entry and the effective use and continued development of advanced STEM skills.

Table 2.10. Selected interventions supporting career entry and effective use of skills

Approach	Example	Principal policy contribution
1. Building shared routes and suitable roles between higher education and employment	NSF Regional Innovation Engines, United States; industry-university contract departments, Korea; Women in AI Australia	Help organisations identify productive applications for advanced STEM skills, create suitable opportunities and improve the visibility of education and career routes through shared research, infrastructure, education and professional networks.
2. Widening access to paid professional experience during education	Generation STEM Links, Australia	Enable learners to apply and demonstrate advanced STEM skills through paid, substantive work before completing their education, particularly where financial circumstances or limited networks restrict access to professional experience.
3. Supporting the transition into a first suitable professional role	GRIT and GRIT@Gov, Singapore; Japan Internship Program	Reduce recruitment uncertainty associated with limited previous employment or unfamiliar international qualifications and enable candidates to demonstrate their competence through substantive work.
4. Combining recruitment with onboarding, effective skills use and continued development	GradStart, Ireland	Connect recruitment with organisation-specific learning, mentoring, substantive responsibilities and progression towards greater autonomy and specialist competence.

1. Building shared routes and suitable roles between higher education and employment

Higher education institutions, employers and other organisations can collaborate around shared research, technologies, infrastructure and professional opportunities. Such collaboration can help employers identify productive applications for advanced STEM skills, create suitable roles and provide learning and research environments that individual organisations could not sustain alone. It responds to the finding in Chapter 1 that apparent shortages may reflect limited demand, too few suitable roles or insufficient organisational capacity to use advanced STEM skills, rather than too few graduates. Its purpose is therefore broader than aligning graduate supply with current vacancies.

The United States National Science Foundation (NSF) Regional Innovation Engines programme illustrates a place-based approach. It supports long-term regional partnerships, referred to as Engines, among universities, companies, public bodies, non-profit organisations, workforce providers and community partners. These partnerships connect use-inspired research, technology development, education and employment around defined technological fields and regional economies. The first ten Engines were announced in 2024, followed by twelve additional Engines spanning twenty states in July 2026. Each initially receives USD 15 million over two years and may receive up to USD 160 million over ten years, subject to progress against defined milestones. The programme covers fields and applications including semiconductors, artificial intelligence, quantum technologies, biotechnology, advanced manufacturing, energy systems and critical materials (NSF, 2026^[131]; NSF, 2026^[132]).

The regional model responds to the uneven distribution of research infrastructure, advanced STEM skills and suitable work. A region may contain relevant universities, facilities, workforce providers and firms but lack the relationships needed to connect them. Smaller firms may also be unable to maintain specialist infrastructure or identify independently how advanced STEM skills could support new activities. The Engines provide a structure through which participating organisations can define shared research, innovation and workforce priorities. Universities can contribute teaching, research and infrastructure

serving several employers; firms can contribute technological problems and professional settings; and workforce and community organisations can connect learners from different backgrounds with emerging opportunities.

The Upstate New York Energy Storage Engine illustrates how this collaboration may operate in practice. Its planned activities include paid internships and applied research across laboratories, manufacturers, utilities and research organisations, supported by mentoring, professional networks and leadership activities (Griffiss Institute, 2026^[133]). Such collaboration can pool specialist staff and facilities, enable smaller organisations to participate in research and recruitment, and give learners access to several employers and professional settings. Movement among participating organisations may circulate knowledge and improve matching rather than indicate unsuccessful retention.

Public investment may be justified where shared infrastructure, research and workforce development produce benefits that individual organisations cannot finance or capture alone. Employers should nevertheless invest in the research, education and professional-development arrangements from which they benefit. Otherwise, the partnership may become primarily a publicly financed recruitment mechanism. Education and professional learning should remain connected with recognised qualifications and broadly applicable disciplinary, interdisciplinary, transversal and professional competence. Monitoring should examine whether the partnerships create substantive roles, widen access across regions and learner groups, strengthen employer capacity and remain sustainable beyond dedicated funding.

Korea's industry-university contract departments provide a more direct connection between higher education and employment. Established through agreements between higher education institutions and companies or public organisations, employment-linked departments offer curricula developed with participating employers and defined routes to employment for learners who meet the relevant academic and recruitment requirements (Min, 2026^[134]). In 2022, Korea had 795 contract departments, including 613 at universities and 182 at junior colleges. Although the model initially focused mainly on continuing education for existing employees, it has expanded to include employment-linked programmes for new entrants in fields such as semiconductors, batteries, artificial intelligence, communications, mobility, defence, aerospace and biotechnology (Park and Choi, 2022^[135]; Japan Science and Technology Agency, 2026^[136]).

Contract departments can make the connection between programme content and an intended employment destination more visible. Employers gain earlier access to potential recruits and can observe their performance through projects, internships and other interactions, potentially reducing reliance on directly comparable professional experience. Close employer involvement also creates risks. Higher education institutions remain responsible for curriculum coherence, assessment and qualification standards, while organisation-specific preparation should build on scientific, mathematical, engineering and methodological foundations that remain useful as technologies and production systems change.

Regional and multi-employer arrangements can make contract departments more accessible to smaller and mid-sized firms. Korea's Regional Innovation System & Education arrangements support regional contract departments through which firms can contribute to shared curricula, learner mobility and other forms of provision instead of financing separate programmes (Son, 2026^[137]). Employer-linked routes may nevertheless affect the future supply of academic researchers and educators if attractive and predictable employment draws graduates away from doctoral education and academic careers. Employer co-investment may therefore need to extend to doctoral education, laboratories, research collaboration and movement between higher education and employment.

Professional networks provide a less formal way to connect people with opportunities. Women in AI Australia links girls and women across education, employment and community settings, including in regional and remote communities, through mentoring, events and cross-sector networks (Women in AI Australia, n.d.^[23]). Its contribution lies in building awareness and professional connections that may support later access to education, professional experience or employment, rather than providing formal matching

or placements. Monitoring should examine geographical reach, participation in mentoring and networks, subsequent access to professional experience and whether these connections lead to identifiable educational or employment opportunities.

Together, the examples illustrate different forms and scales of collaboration. Regional innovation partnerships can pool research, infrastructure and employer capacity; contract departments can create direct routes between programmes and employment; and professional networks can make opportunities and potential candidates more visible. Their contribution depends on whether they lead to substantive work, include smaller employers and learners from different backgrounds, and develop skills and experience that remain useful across organisations, sectors and regions.

2. Widening access to paid professional experience during education

Paid professional experience during education can enable learners to apply and demonstrate advanced STEM skills while widening access for those unable to undertake unpaid work. Differences in finance, geography and professional networks affect who can obtain the work samples, references and contacts that employers later recognise. Paid projects can therefore connect academic and professional learning and provide evidence of competence before learners complete their education.

Australia's Generation STEM Links illustrates how an intermediary can support such opportunities. Operated by CSIRO in New South Wales, it connects learners in the final years of university and vocational education with STEM employers through flexible, project-based internships of approximately 200 hours over up to six months. Employers hire and pay the learner, while CSIRO supports recruitment, matching and the relationship with the host organisation. Employers receive a payment after successful completion to offset part of the cost (CSIRO, n.d.^[138]).

The initiative addresses connected constraints affecting learners and employers. Learners need opportunities to apply and demonstrate advanced STEM skills, while employers need evidence that applicants can use their knowledge beyond assessed academic work. An intermediary can help smaller employers translate a scientific or technical need into a feasible project, recruit a suitable learner, support onboarding and maintain contact during the placement. Substantive project work can reduce uncertainty in later recruitment and help employers identify how advanced STEM skills could contribute to their organisation.

The value of paid experience depends on both accessibility and educational quality. Remuneration reduces reliance on learners' ability to undertake unpaid work, but barriers related to location, scheduling, transport, disability and care responsibilities may remain. Flexible scheduling and assistance with participation costs may therefore still be needed. Employers remain responsible for remuneration, suitable work, supervision and feedback. Higher education institutions can help learners relate the experience to their programme and document the competence developed. Where a placement carries credit, they remain responsible for its learning objectives and academic assessment.

Professional experience can demonstrate the four competence dimensions in connected ways. Project outputs may provide evidence of disciplinary competence; work involving several fields may demonstrate interdisciplinary competence; collaboration and problem-solving may show transversal competence; and responding to organisational, ethical and regulatory requirements may demonstrate professional competence. Evidence should identify each learner's contribution, particularly where work is undertaken in a wider team.

Work samples, project records, portfolios, supervisor feedback and structured accounts of responsibility can show what learners did, which methods they applied and how they responded to professional requirements. Where proprietary information is involved, the evidence should demonstrate the underlying competence without disclosing confidential material. It should also remain interpretable beyond the host

organisation. A generic statement that a learner completed an internship, or evidence showing only familiarity with one employer's internal systems, may have limited value in wider recruitment.

Public support may be justified where it widens access, enables smaller employers to participate or creates opportunities that would not otherwise exist. It is less justified where it replaces professional experience or entry-level work that employers would otherwise finance. Monitoring should examine who applies and participates, remuneration and practical accessibility, the substance of project work, individual responsibilities, supervision and the evidence produced. It should also assess whether the programme reaches learners who would otherwise have limited access and whether employers beyond the host organisation recognise the competence demonstrated.

3. Supporting the transition into a first suitable professional role

At the transition into employment, recent graduates and internationally educated candidates may be excluded because employers lack familiar evidence of their competence. Employers may rely on previous employment, familiar qualifications or established networks even where candidates have relevant foundations. Supported first professional opportunities can reduce this uncertainty by allowing employers to assess candidates through substantive work.

Singapore's GRaduate Industry Traineeships (GRIT) and GRIT@Gov provide three- to six-month paid traineeships for recent graduates without previous full-time employment. GRIT places graduates with private-sector organisations, while GRIT@Gov provides opportunities in public agencies. The initial GRIT offer included up to 800 places in areas such as information and communication technology, manufacturing and financial services. Trainees receive a monthly allowance, financed jointly by government and the host organisation. The programmes allow graduates to demonstrate their performance and develop organisation- and sector-specific knowledge through supervised work (Ministry of Manpower, 2025^[139]; Public Service Division, 2025^[140]).

Public co-financing may encourage employers to create first professional opportunities that they would otherwise be reluctant to provide. However, the short duration, below-salary allowance and absence of a standard employment relationship create a risk that traineeships replace regular entry-level positions or delay movement into secure work. Monitoring should therefore examine whether positions are additional, provide substantive work and lead to stable employment.

The Japan Internship Program addresses uncertainty about internationally acquired qualifications and experience. It connects overseas-based professionals, including final-year learners, engineers and researchers, with Japanese small and medium-sized and regional firms. The programme helps employers identify where participants' advanced STEM skills could contribute, define suitable projects, match candidates and support onboarding (METI, 2026^[141]; METI, 2026^[142]).

For example, an engineering learner placed with the agricultural research and consulting start-up Nosya examined international smart-agriculture technologies and contributed to a pest-forecasting application. The project enabled the employer to assess the participant's technical and interdisciplinary contributions rather than relying on the qualification title alone (METI, 2023^[143]). Intermediation is valuable only where participants undertake substantive work corresponding to their skills, rather than being assigned mainly routine, translation or communication tasks.

The Singapore programmes create first opportunities for graduates without full-time experience, while the Japanese programme helps employers assess competence developed through less familiar international routes. Public intervention is most clearly justified where it creates additional opportunities or strengthens employers' capacity to assess candidates they might otherwise exclude. Monitoring should examine work content, supervision, subsequent employment and whether experience remains useful beyond the host organisation. It should also assess whether employers become able to recruit and use these candidates' advanced STEM skills without continued public support.

4. Combining graduate recruitment with structured development

Recruitment does not complete the transition into professional work. Graduates may have strong disciplinary and methodological foundations but still need to learn organisational processes, technologies, standards and regulatory requirements. They also need access to suitable expertise and progressively more complex and responsible work.

Ireland's *GradStart* connects graduate recruitment with structured workplace development. It supports eligible firms to recruit graduates to full-time positions lasting 24 months and provides a subsidy of up to 50% of salary costs. Each graduate undertakes a project linked to the firm's growth plan and works with an in-company mentor. Firms must demonstrate that the position contributes to their strategic development and that they can provide the infrastructure, supervision and workplace access required (Enterprise Ireland, n.d.^[144]).

The two-year period provides time for onboarding, supervised work and progression towards greater responsibility. Its value nevertheless depends on whether the graduate's work becomes more complex and whether mentoring provides meaningful guidance and feedback. A growth project can help a smaller firm identify how advanced STEM skills contribute to its development, but only if the graduate has access to the technologies, information, complementary expertise and authority needed to undertake substantive work.

Public support may be justified where it enables firms to create positions, introduce new functions or develop their capacity to use advanced STEM skills. It is less justified where recruitment and employee development would have occurred without assistance. Employer co-financing and a documented growth project can reduce, but not eliminate, this risk.

Monitoring should examine not only whether a position is created, but also the work undertaken, changes in complexity and responsibility, the quality of mentoring and feedback, contributions to the growth project and employment after the supported period. It should also assess whether the competence and experience developed remain useful beyond the participating firm.

Lessons across the approaches

Career entry and effective skills use form a connected employer process. Employers need to identify where advanced STEM skills could contribute, interpret and validate available competence, recruit candidates with suitable foundations, provide organisation-specific learning and allocate substantive work. As Chapter 1 shows, an observed recruitment difficulty or apparent shortage does not identify which of these points is constraining outcomes.

Shared routes among higher education institutions, employers and other organisations can help create suitable roles and connect research, infrastructure, education and occupational knowledge. They can be particularly valuable where smaller employers lack the capacity to identify productive applications for advanced STEM skills or provide professional experience independently. These arrangements should create sustainable opportunities and preserve competence that remains applicable across employers, technologies, sectors and regions.

Paid professional experience can widen access to opportunities to apply and demonstrate advanced STEM skills. Accessibility also depends on location, scheduling, transport, disability-related support and care responsibilities. The value of the experience depends on substantive technical or analytical work, suitable supervision, feedback and credible evidence of individual contribution. This responds to the unequal access to evidence-producing opportunities identified in Chapter 1.

Supported first-professional roles can help employers assess candidates with limited previous employment or unfamiliar qualifications. Public support is most justified where it creates additional opportunities, reaches candidates facing barriers or helps employers develop recruitment capacity. Safeguards are

needed to prevent traineeships and subsidised roles from replacing regular employment, providing mainly routine tasks or leading to repeated temporary placements.

Recruitment support alone does not ensure effective skills use. Employers need to provide onboarding, complementary expertise, suitable technologies, substantive responsibilities and opportunities for greater autonomy, specialist depth and professional responsibility. Mentoring contributes only where it provides relevant guidance and feedback. These conditions connect recruitment with the employer-level bottlenecks concerning onboarding, work organisation, continued development and retention discussed in Chapter 1.

Higher education institutions can communicate programme outcomes, provide substantive projects and professional experience and collaborate with employers in programme design and delivery. Employers nevertheless remain responsible for recruitment, organisation-specific learning, task allocation, working conditions and advancement. Public intervention has a clearer rationale where unequal access, shared benefits or limited organisational capacity produce underinvestment than where it subsidises ordinary employer responsibilities.

Monitoring should follow the connected process rather than individual activities alone. It should examine access to professional experience, the evidence of competence produced, recruitment and onboarding practices, task content, autonomy, continued development, retention and movement into stable work. It should also assess whether roles are additional, whether advanced STEM skills are applied effectively and whether the experience developed remains portable. This can help determine whether interventions address the distinct career-entry and skills-use bottlenecks identified in Chapter 1 rather than merely increase placements, traineeships or supported hires.

Conclusion

The policy priorities examined in this chapter address constraints affecting individuals, higher education institutions, employers and the wider system. These constraints shape the development, demonstration, recognition, effective use and renewal of advanced STEM skills. The priorities concern entry, persistence and completion in high-quality STEM higher education; progression to advanced STEM expertise and skills renewal across working life; programme renewal; and career entry and the effective use and continued development of advanced STEM skills. They are not a standard set of measures for every country, region or field. Their relevance depends on the constraint, population and location concerned, the wider public interest, and the responsibilities and capacity of the actors involved.

The same observed problem may arise from different causes and therefore require different responses. Some causes may not be directly observable from available indicators. Low entry may reflect limited preparation, information, financial feasibility or institutional capacity. Restricted progression may result from unclear routes, weak recognition, unequal access to research experience or insufficient teaching, research and supervisory capacity. Recruitment difficulties may reflect an insufficient supply of particular advanced STEM skills, but may also arise from narrow entry requirements, difficulty interpreting qualifications, demand for experienced workers, limited onboarding or unattractive employment conditions. Diagnosis should test competing explanations using evidence from individuals, institutions, employers and public authorities, while recognising remaining uncertainty. Policy should address the mechanism producing the problem rather than assume that expanding participation or provision is appropriate.

Effective interventions also need to account for connections with earlier and later points. Increasing entry requires sufficient teaching, infrastructure and learner support for persistence and completion. Progression routes require transparent requirements, credible recognition and sufficient capacity in receiving programmes. Shorter learning can support skills renewal where it is coherent, assessed and connected with recognised destinations. Programme renewal needs to preserve disciplinary and methodological foundations while developing the interdisciplinary, transversal and professional competence required by

the programme's purpose. Career-entry measures need to lead to substantive work, effective onboarding and continued development. Otherwise, interventions may leave connected constraints unresolved or transfer them elsewhere.

Implementation requires sustained pedagogical, organisational and resource capacity. Additional places, flexible routes, research opportunities, partnerships or supported employment will have limited effects without the staff, infrastructure, leadership, supervision and co-ordination needed to deliver them. Temporary funding may establish useful activities without securing the responsibilities and resources required to sustain them. Policy ambitions therefore need to be matched with implementation capacity and longer-term institutional and organisational commitments.

Such capacity and the opportunities it supports are unevenly distributed. Corporations, universities and regions with strong infrastructure, research environments, professional networks and organisational capacity may provide more substantive roles and development opportunities. This concentration can reinforce disparities among employers and regions, restrict opportunities for graduates unable to relocate and leave advanced STEM skills underused in smaller organisations or less well-resourced settings.

The distribution of employment opportunities can also affect the renewal of higher education and research capacity. Attractive opportunities outside higher education may draw graduates away from doctoral education and academic careers. Movement between sectors can support knowledge exchange and productive skills use, but a sustained reduction in doctoral candidates, researchers and academic staff may weaken future teaching, supervision and research capacity. Policy responses should therefore consider the distribution of career opportunities, the use and continued development of advanced STEM skills across employment settings, and the effects of employment patterns on higher education and research capacity.

Addressing these connected constraints requires clear responsibilities and co-ordination among the actors concerned. Chapter 3 examines how this can be done, in particular how policymakers can diagnose constraints, distinguish among individual-facing, higher education institution, employer and system-level causes, and select and sequence appropriate responses.

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3

Developing a strategy for advanced STEM skills

This chapter examines how strategies for advanced science, technology, engineering and mathematics (STEM) skills can support policy co-ordination, priority setting and continuing policy learning across education, research, innovation and employment. It presents a strategic approach for diagnosing constraints, selecting and sequencing responses, clarifying responsibilities, and aligning policy ambitions with implementation capacity and resources. The chapter concludes with eight areas for policy action that can be used to guide the design, implementation and evaluation of a strategy for advanced STEM skills.

Key issues

A strategy for advanced STEM skills can connect policy portfolios and levels of government, clarify responsibilities, combine resources and strengthen implementation. This requires a clear diagnosis, agreed priorities, defined responsibilities and adequate, sustained resources.

Policy priorities need to be realistic and supported by sufficient capacity. Ambitious objectives will have limited effects without adequate educators, technical staff, supervision, infrastructure, learner support and institutional leadership. Expanding participation, advanced study or skills-renewal provision without these conditions may limit access to high-quality learning and risk to move constraints to completion, progression, and employment.

Monitoring, evaluation and policy learning are essential to improve interventions. Monitoring can track participation, competence development, progression, skills use and renewal across fields, places and population groups. Evaluation can examine implementation, interactions and unintended effects, including whether constraints are removed or transferred. Higher education institutions support policy learning by interpreting evidence, identifying implementation challenges, improving practice and informing policy adaptation.

International mobility and collaboration matter for advanced STEM skills. As global competition for talent intensifies, strategies should connect attraction with recognition of qualifications and experience, integration into education, research, employment and society, conditions for retention and continued development, and opportunities for return and collaboration. They should coordinate responsibilities across policy portfolios, consider effects on origin and destination countries, and support mutually beneficial talent circulation and partnerships.

The development and effective use of advanced STEM skills depend on policy decisions made across education, science, technology, innovation and employment portfolios. Learners need access to suitable preparation, high-quality programmes and viable routes to advanced study and skills renewal. Higher education institutions need sustainable pedagogical, organisational and resource capacity. This includes qualified academic and technical staff; effective curriculum design, teaching, assessment, feedback and supervision; programme leadership and co-ordination; connected academic, practical and psychosocial support; suitable infrastructure and research environments; and the data and analytical capacity to identify barriers, monitor learning and progression, and improve programmes. Employers need to recognise the resulting competence, recruit people with appropriate foundations and support their transition into work so that advanced STEM skills are used and continually developed.

A strategy for the development of advanced STEM skills can establish shared priorities, clarify responsibilities and enhance co-ordinated action. It can support decision-making under uncertainty by sustaining long-term capacity while allowing priorities to be adjusted as needed. The contribution of a strategy depends on the choices made beneath its broad objectives. A strategy can support evidence-based priority setting, connect complementary interventions, assign responsibilities and sustain attention over time. The STEM Education Strategic Plan presented by the European Commission illustrates these contributions. Its objectives and targets can focus political attention, support co-ordination and encourage action towards shared objectives.

Broad strategic objectives can establish direction, but they do not determine which constraint should be prioritised, which mechanism should be addressed or which actor should act. Nor can they remove uncertainty about future technological developments, applications or demand for particular combinations of competence. The following sections set out how policymakers can diagnose constraints, select and sequence appropriate responses, align responsibilities and ambitions with implementation capacity, and

use monitoring, evaluation and policy research to support continuing policy learning. They examine when a strategy for advanced STEM skills may be useful and present eight areas for policy action to guide design, implementation and monitoring.

International mobility and collaboration matters for advanced STEM skills. In a context of increasing global competition for advanced STEM talent, strategies may seek to attract international learners, researchers and professionals, but should connect recruitment with the recognition of qualifications and experience, integration into education, research, employment and wider society, suitable conditions for retention and continued development, and opportunities for return and ongoing collaboration. These elements involve responsibilities across policy portfolios. Strategies should also consider the effects of mobility on origin and destination countries and support mutually beneficial circulation and international collaboration.

Diagnosing the constraint before selecting a response

Indicators of enrolment, graduation and employment can show general patterns and changes across countries, regions and periods. When sufficiently detailed, they can show whether participation is increasing, how representation differs among population groups, whether graduate numbers are changing and whether employment is growing or declining in broadly defined fields and occupations. These indicators can identify developments that require closer examination and help monitor progress towards broad policy objectives. However, they cannot explain why these patterns have occurred. Explaining these patterns requires closer analysis of the mechanisms involved. These may arise in areas that involve different responsibilities across public authorities, higher education institutions and employers.

An observed pattern may indicate a possible bottleneck, but it does not establish whether a significant and avoidable constraint exists, identify its cause or determine the appropriate response. Diagnosis should test competing explanations, establish whether and for whom a bottleneck exists, distinguish contributing constraints by field, level, population and location, and identify the mechanisms through which they operate. A sufficiently specific diagnosis can establish whether public intervention is justified, where responsibility for addressing the identified constraints lies, and which actors have the relevant instruments and implementation capacity.

The questions presented in Table 3.1 can guide diagnosing a constraint before selecting a response. The context-specific relevance of these questions depends on the responsibilities and decision-making scope of the actor undertaking the diagnosis. Public authorities and education planners may apply them to system-wide patterns, resource allocation and regulatory conditions, while higher education providers may apply them to programme design, teaching, assessment, learner support and institutional capacity. The questions remain broadly the same, but their application, evidence and possible responses depend on the actor and context.

Table 3.1. Common questions for diagnosing a constraint before selecting a response

Diagnostic question	What to examine	What the diagnosis should establish
What is the observed pattern?	Analysis may concern entry, persistence, completion, progression, recruitment, skills use, skills renewal, advancement or retention.	A precise description of the pattern, distinct from its possible causes and proposed responses. Where international mobility is relevant, analysis should also examine effects on origin and destination countries.
Who is affected?	Evidence should establish whether learners, graduates or workers with different characteristics or circumstances differ in how they are affected by the pattern.	Which groups are affected and how they are affected.
Which mechanisms could explain the pattern?	Several mechanisms may interact, and not all may be easily detectable.	The mechanisms contributing to the pattern, how they interact and whether their effects become visible at a different stage or level.

Diagnostic question	What to examine	What the diagnosis should establish
What is the evidence?	Diagnosis should combine evidence from education systems, higher education institutions, learners, graduates, workers and employers.	What does the available evidence explain; what evidence is missing and how could it be obtained.
Which policy instruments can be used?	Relevant instruments may include funding, regulation, information, guidance, quality assurance, recognition arrangements, institutional capacity building, learner support, support or incentives for employer action, and co-ordination among actors.	Which instruments address the diagnosed pattern and underlying mechanisms and why they are more appropriate than alternative responses.
How should action be combined and sequenced?	A response may depend on complementary action by several actors. Policy should consider how the proposed intervention interacts with existing arrangements, which conditions must be established for it to operate as intended, and whether action at one point could create additional pressure elsewhere.	Which actions should precede, accompany or reinforce others and how additional pressure elsewhere can be avoided.
What capacities and resources are required?	Responsibilities are distributed and several actors may need to act where constraints are connected or mutually reinforcing. Analysis should distinguish between capacity that already exists, capacity that can be redirected and capacity that must be developed before an intervention can operate effectively or at scale.	Which actors are relevant; which capacities and resources already exist, which can be redirected and which must be developed before or during implementation.
What outcomes and potential trade-offs should be monitored?	Monitoring should examine whether the identified constraint is reduced, whether effects differ across groups, whether the intended competence and educational quality are maintained, and whether the intervention produces unintended effects or transfers pressure to another part of the educational or professional route.	The baseline, intended outcomes, distributional effects and potential trade-offs.

Source: Authors based on discussions in the Mutual Learning Group on Advanced STEM skills development in higher education.

International policy inventories can complement national diagnosis by showing which approaches have been adopted in other contexts. UNESCO's Global Observatory of Science, Technology and Innovation Policy Instruments (GO-SPIN) and the EC-OECD STIP Compass provide information on national science, technology and innovation policies and instruments, including initiatives related to STEM skills. Used alongside national evidence and stakeholder engagement, these resources can help policymakers identify potentially relevant instruments, compare the composition of policy responses and locate areas receiving limited attention.

These resources can inform the search for possible responses, but selecting among them still requires analysis of the relevant mechanisms, responsibilities, capacity and context. The questions in Table 3.1 can help to structure this analysis. Several constraints may interact, relevant evidence may be held by actors who are not responsible for addressing the constraint, and a pattern visible in one location may originate elsewhere. Chapter 1 distinguishes individual-facing constraints from those arising within higher education institutions, employers and wider system arrangements, and applies these categories across the five bottlenecks. This distinction helps locate the constraints, identify the actors with the relevant instruments and capacity, and determine whether complementary or sequenced action is needed.

A sufficiently specific diagnosis provides the basis for evaluation. It identifies the initial situation, the mechanism an intervention is expected to change, the actors responsible for implementation and the outcomes through which progress can be assessed. The following section examines how evaluation and policy research can test these assumptions and support policy learning.

Evaluation and policy research as foundations for policy learning

Evaluation tests the explanations and expected mechanisms established through diagnosis. Outcomes in the development and effective use of advanced STEM skills are rarely explained by a single factor. As discussed in Chapter 1, learners enter programmes with different preparation, resources, prior opportunities and personal circumstances. Institutions differ in staffing, infrastructure, programme design and learner support. Employers differ in recruitment, onboarding, management and work organisation. These conditions interact, and an intervention may influence several outcomes at different points in time. Evaluation therefore needs to examine not only whether outcomes change, but also how change was expected to occur and the conditions under which the intervention was implemented.

Policy research has an important role in this process. It can develop and validate measures of learning and competence; examine curriculum, teaching, assessment and programme design; identify mechanisms affecting entry, persistence, completion, progression and skills renewal; and analyse recruitment, onboarding, work organisation, skills use, continued development, advancement and retention. It can also examine how governance, funding, regulation and institutional and organisational capacity shape these outcomes across education, research and employment. Drawing on education, labour-market, organisational, workplace, and science, technology and innovation research, it can help distinguish constraints arising from individual circumstances from those arising through institutional arrangements, employer practices or wider system conditions.

Policy learning requires sustained connections among researchers, policymakers, higher education institutions, employers, learners and workers. Evaluation questions should correspond to the constraint being addressed, while findings should be available in forms that can inform funding, regulation, programme design and organisational decisions. Incorporating evaluation into policy design can preserve baseline evidence, document implementation and create opportunities for comparison that may no longer be available if evaluation begins only after implementation.

Evaluation should be integrated into policy design rather than introduced only after implementation. Public authorities and institutions need the capacity to formulate evaluable objectives, identify the expected sequence of change, establish appropriate comparisons, examine implementation and follow outcomes beyond an intervention's immediate effects. Without a clear account of the constraint being addressed and how an intervention is expected to affect learning, progression, employment or skills use, it is difficult to determine whether weak outcomes reflect an incorrect diagnosis, inadequate implementation, insufficient time, limited institutional or organisational capacity, or an intervention that is ineffective even when delivered as intended. Box 3.1 summarises the principal methodological challenges involved.

Box 3.1. Methodological challenges in evaluating policies for the development and effective use of advanced STEM skills

Determining whether a policy has improved the development or effective use of advanced STEM skills is rarely straightforward. Observed changes may reflect the intervention, differences among participants and institutions, wider contextual developments or interactions among these factors. Evaluation therefore needs to consider attribution, implementation, the timing of impacts and the extent to which findings apply in other settings.

- **Several interacting conditions may influence outcomes.** Entry, completion, progression and effective skills use are rarely explained by a single condition, making mono-causal explanations generally inadequate. The effect of an intervention may also depend on complementary arrangements. Financial support may make participation feasible but have limited effects where teaching or scheduling remains inaccessible. Employer-provided learning may develop

competence without improving its use where workers lack autonomy or opportunities to apply it. Evaluation therefore needs to distinguish the effects of the intervention from those of the conditions on which its effectiveness depends.

- **Impacts may take time to emerge.** An intervention may influence connected outcomes at different points. Changes in preparation or guidance may affect applications and programme choice before influencing completion. Better onboarding may initially affect role clarity and workplace relationships before influencing performance, skills use or retention. Evaluation should reflect this expected sequence and allow sufficient time for later effects to become visible.
- **Selection bias can affect observed outcomes.** Selection bias arises when participants differ systematically from non-participants in ways that also influence the outcomes being measured. Participants in optional interventions may differ in prior attainment, motivation, available time, financial resources or access to networks. Institutions and employers adopting a policy may likewise differ from non-adopters in capacity, leadership or commitment. Observed differences may therefore reflect these pre-existing characteristics as well as the effects of the intervention.
- **Implementation may vary across settings.** Interventions with the same formal design may differ in staffing, intensity, participant engagement, local leadership and access to complementary support. A weak average effect may conceal effective implementation in some settings and incomplete delivery in others. Differences in outcomes may therefore reflect variation in reach, participation, implementation quality and local adaptation, as well as the effectiveness of the intervention itself.
- **Evidence on effects, mechanisms and implementation can be difficult to combine.** Quantitative evidence can estimate changes in outcomes but may provide limited explanation of why they occurred. Qualitative and process evidence can reveal participant experiences, implementation differences, causal mechanisms and contextual conditions, but may not establish the scale or distribution of effects. Evaluation may need to combine these forms of evidence to determine whether change occurred, how it occurred and under which conditions.
- **Longitudinal evidence may be limited.** Effects on progression, employment, skills use, advancement and retention may emerge several years after participation. Short observation periods can capture immediate changes while missing whether they persist or influence later educational and occupational routes. Following outcomes over time may be constrained by fragmented data, participant attrition and difficulties linking education and employment records.
- **Pilots provide limited evidence of effectiveness at scale.** Pilots can show whether recruitment, delivery and evaluation arrangements are feasible and help identify possible mechanisms and necessary adaptations. However, their participants, staff and institutions may not represent those involved in wider implementation. Expansion may alter staffing requirements, participant composition, delivery quality and institutional ownership. Pilot findings therefore do not establish effectiveness or scalability on their own.
- **Findings may not transfer directly across contexts.** Evidence from one institution, field, region or population does not establish that an intervention will produce the same effects elsewhere. Differences in governance, funding, institutional capacity, learner composition and labour markets may alter how it operates. Assessing wider applicability requires attention to the mechanisms and contextual conditions on which effects depend, the adaptations that can be made without weakening essential functions, and the capacities required for expansion.

Source: Skivington et al. (2021^[1]), "A new framework for developing and evaluating complex interventions: Update of Medical Research Council guidance", <https://www.bmj.com/content/374/bmj.n2061>; and Unlu, F. et al. (2021^[2]), "Can quasi-experimental evaluations that rely on state longitudinal data systems replicate experimental results?", <https://doi.org/10.1002/pam.22295>.

The evaluation method should match the policy question, intervention and context. Experimental, quasi-experimental, longitudinal, comparative, statistical and qualitative approaches may be used separately or in combination. The appropriate choice depends on the nature and scale of the intervention, how participants are selected, the availability of baseline and comparison data, the timing of expected effects and variation in implementation across settings. No single method is appropriate for every policy question. The strength of the evidence depends on whether the selected design supports credible conclusions about the question being examined and makes its assumptions and limitations explicit.

The methodological challenges summarised in Box 3.1 reinforce the need to connect evaluation with diagnosis, implementation and policy decisions. They also show why isolated interventions may be insufficient where outcomes depend on complementary conditions, responsibilities are distributed across policy areas and effects emerge across several stages. A strategic approach can provide a framework for connecting these elements, aligning action with implementation capacity and supporting policy learning over time.

Why a strategy for advanced STEM skills may be needed

Advanced STEM skills are developed, demonstrated, recognised, used and renewed through connected education, research and employment systems. Constraints affecting these processes may originate in school preparation, higher education capacity, programme organisation, access to research and professional experience, recognition arrangements, recruitment practices, onboarding, work organisation, employment conditions or access to skills renewal. Responsibility for addressing them is consequently distributed across education, research, innovation, employment, industrial and regional policy and among public authorities, higher education institutions, research organisations, employers and professional bodies.

A strategy can provide value where these distributed responsibilities and interventions need to be connected around a shared diagnosis. It can establish a common understanding of the advanced STEM skills concerned, identify where consequential constraints arise and clarify how the differentiated responsibilities of the relevant actors should be aligned. It can also support continuity where developing institutional, educational, research or employer capacity requires action extending beyond individual programmes or short funding periods.

A separate STEM strategy is not necessarily required where existing education, research, employment and innovation strategies already provide a shared diagnosis, priorities, clear responsibilities, sustained implementation capacity and connected monitoring. The relevant question is whether existing strategic arrangements can address the identified constraints coherently across policy domains.

The purpose of diagnosis is not to demonstrate that every country has a general shortage of advanced STEM skills or that participation should increase across all STEM fields. It is to determine which disciplinary, interdisciplinary, transversal and professional competence is required; in which fields, qualification levels, occupations and locations; which populations and organisations are affected; and which mechanisms produce the observed constraint. Low entry, weak completion, limited progression, recruitment difficulties or low participation in continuing education do not by themselves establish their causes or the appropriate response.

A strategy should therefore begin with observed outcomes and examine competing explanations. Recruitment difficulties, for example, may indicate an insufficient availability of particular advanced STEM skills, but may also reflect narrow requirements, demand for directly comparable experience, location, pay and working conditions, weak onboarding or limited organisational capacity to use available competence. Low progression to advanced study may reflect financial, informational or institutional barriers, but may also result from attractive employment opportunities. Limited participation in skills renewal may arise from

unsuitable provision, uncertain recognition, cost, time constraints, weak employer support or limited opportunities to apply the learning.

This diagnosis should be differentiated by field, level, population and location. Aggregate STEM indicators can support political direction and comparison, but cannot identify the particular competence required or the mechanism producing a constraint. The strategy should therefore combine evidence from education, research, employment, employers and workers and examine qualifications, experience, tasks, actual skills use, working conditions and progression over time.

A shared diagnosis provides the basis for selecting and sequencing priorities. It should identify which actors possess the relevant authority and instruments, what implementation capacity is required and how action at one point may affect another. Increasing entry without sufficient teaching and learner support may transfer the constraint to persistence and completion. Expanding advanced study without adequate supervision and research infrastructure may delay completion or weaken quality. Increasing graduate supply without suitable roles, effective onboarding and substantive work may transfer the constraint into employment and skills underutilisation.

A strategy should consequently be selective rather than comprehensive by default. It need not introduce a new intervention for every bottleneck or reproduce activity already functioning effectively under general education, employment or social policy. Its purpose is to identify the constraints that require connected or additional action, establish responsibilities and resources, and monitor whether advanced STEM skills are developed, recognised, used and continually renewed. Countries may adopt a dedicated STEM education strategy, incorporate advanced STEM skills into a broader skills, science, innovation or industrial strategy, or develop strategies for particular technologies and fields. These formats can coexist.

The gains and potential trade-offs of a national strategy

A national strategy for advanced STEM skills can provide a common framework for policy areas and institutions that would otherwise act separately. It can connect the foundations developed in school with routes through VET and higher education, relate initial education to skills renewal, and bring research training into a wider account of advanced STEM skills. It can also establish links with research, innovation, industrial and regional policies that influence where advanced STEM skills are developed and used.

The first potential gain is a shared and differentiated diagnosis. A strategy can bring together evidence on participation, learning, progression, research capacity, educational and professional destinations, and the application of advanced STEM skills. This can help distinguish among constraints affecting different fields, qualification levels, regions and population groups. It can also enable governments to test whether an observed difficulty arises primarily from weak educational foundations, unequal access, insufficient institutional capacity, limited progression routes, conditions in research training, or constraints on the effective use of advanced STEM skills after education.

A second gain is the possibility of connecting action across the five bottlenecks. Measures intended to widen entry may have limited effects if learners encounter weak teaching or insufficient support after admission. Expansion at postgraduate level may move a constraint into completion if research funding, infrastructure and supervision do not expand accordingly. Short learning may increase participation in continuing education without enabling skills renewal if its level, recognition and relationship with larger qualifications remain unclear. A strategy can make these dependencies visible and support combinations of action that would be difficult to co-ordinate through isolated programmes.

A third gain is clearer direction and responsibility. A strategy can identify a limited set of national priorities while allowing institutions to adapt their responses to particular fields and learners. It can clarify which public authorities are responsible for funding, regulation, quality assurance, qualifications, data and research, as well as which responsibilities rest with education and research institutions. It can also identify

where co-operation with employers and other actors is required without transferring their responsibilities to education providers.

Finally, a strategy can provide continuity and a basis for policy learning. Many changes to advanced STEM education require sustained commitments. Preparing qualified teachers and academic staff, building research environments, developing specialist infrastructure, renewing programmes and establishing new progression routes cannot normally be achieved through short interventions. A strategy can provide a longer time horizon, while periodic monitoring and review can allow priorities to change as evidence, technologies and societal needs develop. These gains are accompanied by two potential trade-offs.

The first concerns the relationship between strategic breadth and sufficiently specific diagnosis. A broad strategy can give STEM political visibility and connect policy across educational stages and government portfolios. At the same time, it can encourage STEM to be treated as a sufficiently coherent category for policy action. Aggregate patterns may conceal major differences among disciplines, qualification levels, types of competence, regions and population groups. An apparent shortage in one specialised field does not establish a need for general expansion across STEM, just as weak participation in one educational route does not show whether the principal constraint lies in preparation, programme capacity, financial support or subsequent opportunities.

A broad strategy may therefore encourage expansion across STEM without identifying the location or cause of the constraint. Conversely, it may develop narrowly specialised provision around uncertain forecasts of technological or occupational demand. Both responses can reduce adaptability. General expansion may direct resources towards fields in which education supply is not the principal constraint, while premature specialisation may produce programmes dependent on a particular expectation of technological development or employer demand.

A strategy can manage this trade-off by combining common direction with field- and level-specific diagnosis. Priorities should identify the mechanism they are intended to change and the evidence against which progress can be assessed. Investments in emerging fields should retain strong disciplinary and methodological foundations, enabling learners to move between applications and adjacent areas as technologies develop. Periodic review should revisit assumptions about demand rather than treating an initial forecast as a fixed basis for programme design or capacity expansion.

The second trade-off concerns the relationship between political visibility and deliverable institutional commitments. A national strategy can convene actors, increase attention and establish ambitions that extend beyond individual programmes. However, political visibility, co-ordination structures and stated objectives do not themselves create the staff, leadership, infrastructure, learner support, supervision, time and organisational authority required for implementation.

Strategies may add initiatives and expectations without addressing the funding, capability and capacity needed to deliver them. New programmes, partnerships and support commitments may be layered onto institutions already facing constraints, while temporary projects may increase activity without creating recurrent capacity. Expansion may then transfer pressure from entry to persistence, completion, progression or research training. Strategic ambition should therefore be matched by an assessment of the resources, expertise, infrastructure and time required. Strategies may need to sequence expansion, concentrate specialist provision, support collaboration or moderate the scale of intervention until sustainable institutional capacity has been developed.

Different formats for national strategies

Countries organise joined-up strategies for advanced STEM skills in different ways, reflecting their governance arrangements, policy priorities and the constraints they seek to address. Three broad formats can be distinguished: dedicated STEM education and skills strategies; broader skills, science, innovation

or industrial strategies that include advanced STEM skills; and strategies focussed on particular fields or technologies. These formats may coexist and complement one another.

Dedicated STEM education and skills strategies

Dedicated strategies explicitly use STEM or an equivalent national term and usually seek to connect action across several stages of education. They can give visibility to relationships that are otherwise divided among school subjects, vocational programmes, higher education, adult learning and non-formal education. Their substantive contribution depends on whether this broad framework is used to select and connect action rather than mainly to assemble existing initiatives under a common label.

The European Commission's STEM Education Strategic Plan provides a supranational example (European Commission, 2025^[3]). Adopted as part of the Union of Skills, it places STEM education within a wider agenda concerned with competitiveness, preparedness and technological development. Its proposed actions include improved STEM skills intelligence, a competence framework, STEM education centres, joint programmes, micro-credentials, capacity building and closer relationships among education, research and industry. The plan seeks to provide shared direction and identify areas in which European co-operation can complement national and regional responsibility.

Finland's LUMA Strategy illustrates a national strategy organised around a long-term vision (Ministry of Education and Culture, 2023^[4]). LUMA refers to natural sciences and mathematics, while the term LUMATE, used in the accompanying action plan, makes the inclusion of technology and technical fields more explicit and corresponds more closely to the international use of STEM. The strategy connects competence in these fields with socially, ecologically and economically sustainable well-being and growth. It is complemented by a LUMATE action plan that identifies more concrete measures, timescales and responsible actors. Its activities are grouped around the development of teaching and education; monitoring, surveys and wider development; and communication and interest. This illustrates how a concise strategic framework can be followed by a more operational plan without requiring the strategy itself to specify every instrument.

Austria's MI(N)Tmachen action plan covers the educational route from early childhood education through school, apprenticeship and higher education (BMBWF, 2023^[5]). MINT is the German-language equivalent of STEM and stands for *Mathematik, Informatik, Naturwissenschaften* und *Technik*, meaning mathematics, computer science, natural sciences and technology. The title MI(N)Tmachen is a play on the German verb *mitmachen*, meaning to participate or join in. The plan brings together regional networks, information and guidance, teacher and programme development, support across educational transitions, research experience, inclusion, interdisciplinary higher education and opportunities for adults. It also situates its educational objectives within Austria's wider research, technology and innovation strategy and higher education planning. It therefore provides an example of a dedicated STEM action plan connected with broader science and innovation objectives.

Germany's MINT action plans connect formal education with non-formal learning environments and regional networks. The MINT-Aktionsplan 2.0 consolidated federal measures across educational stages and organised further action around co-operation between formal and non-formal provision, quality, families, early learning and education research (BMBF, 2022^[6]). The subsequent MINT+ framework, presented jointly by the federal ministries responsible for education and research in 2026, places additional emphasis on coherent education ecosystems, equal opportunities, talent in key technologies and shared responsibility among government, education, research, business and civil society. The "+" signals a broader approach that connects MINT subjects more strongly with creativity, societal questions and other capabilities relevant to innovation, including entrepreneurship. It also links MINT education more closely with Germany's wider innovation and technology policy through the Hightech Agenda Deutschland (BMFTR and BMBFSFJ, 2026^[7]).

These examples differ in scope and organisation. Finland combines a concise long-term vision with an implementation plan. Austria follows the education route and brings together several forms of provision and support. Germany places particular emphasis on regional and non-formal learning ecosystems, while the EU plan identifies common objectives and areas for co-operation across national systems. In each case, the general gains and trade-offs identified above remain relevant. A dedicated STEM framework needs to distinguish among fields and levels, select among possible actions and establish how institutions will acquire the capacity required for implementation. The evolution of the strategy in Germany illustrates how a national STEM framework can be periodically revised to reflect changing educational, technological and societal priorities rather than treated as a fixed statement of priorities.

Positioning advanced STEM skills within broader national strategies

Advanced STEM skills may also be addressed within a broader national strategy. This may be appropriate where the principal purpose is to connect education and research capacity with economic development, public services, technological transformation or regional specialisation. Relevant formats include national skills strategies, science and innovation strategies, industrial strategies, and strategies for digital or green transitions.

This format can strengthen the connection between advanced STEM skills and their effective use. It can bring educational priorities together with research funding, infrastructure, business investment, procurement, innovation support and regional development. It can also make clearer that skills alone do not produce innovation or productivity. Their application depends on complementary expertise, equipment, organisational capability and opportunities to undertake substantive work.

Ireland's National Skills Strategy, for example, linked education and training with economic and social development, lifelong learning, inclusion, teaching quality and employers' effective use of skills. It treats the relevance of learning to individuals, society and the economy as a shared concern while distinguishing the contributions expected from education providers, employers and public authorities. Not confined to STEM, this form of national skills strategy can accommodate advanced STEM skills within a broader account of participation, learning and use (Department of Education and Skills, 2016^[8]).

Industrial strategies can integrate advanced STEM skills with investment and sectoral development. The United Kingdom's Modern Industrial Strategy, for example, establishes a ten-year framework for increasing business investment in eight growth-driving sectors, supported by dedicated sector plans and measures addressing research and development, infrastructure, skills and regional clusters. The eight sectors are advanced manufacturing, clean energy industries, creative industries, defence, digital and technologies, financial services, life sciences, and professional and business services. In this format, skills development forms one component of a wider account of the conditions required for sectors such as advanced manufacturing, clean energy, digital technologies and life sciences to develop (Department for Business and Trade, 2025^[9]).

Embedding advanced STEM skills in a broader strategy can therefore provide a more complete account of effective use than an education strategy alone. It can connect programme and research capacity with environments in which advanced STEM skills may be applied. Education and science-policy responsibilities should nevertheless remain explicit. Education institutions should not be treated primarily as suppliers of labour for selected sectors, and programme design should not be subordinated to short-term occupational requirements. Where an industrial or economic strategy anticipates substantial expansion in a field, it should also consider the time and resources needed to build teaching, research and supervisory capacity.

Field- or technology-specific strategies: Lessons from national quantum strategies

A third format focusses on a particular scientific field or family of technologies. This may be appropriate where capability depends on specialised research infrastructure, concentrated expertise, long training horizons and close co-ordination among research, education, innovation and technological uptake. National strategies for quantum technologies, artificial intelligence, semiconductors, biotechnology, cybersecurity, advanced materials and clean-energy technologies illustrate this approach. National quantum strategies provide a particularly useful example.

Field- or technology-specific strategies can identify competence and capacity requirements more precisely than a general STEM strategy. They can distinguish between researchers, engineers, technicians and professionals from adjacent fields, while connecting research funding, infrastructure, education and innovation to the maturity and expected development of the field. Their specificity does not remove uncertainty, however. Technologies may develop in directions that differ from initial expectations, and relevant competence may be distributed across established disciplines rather than embodied in a new qualification.

Quantum technologies illustrate these characteristics. Skills in quantum sensing, computing and communication draws on physics, mathematics, computer science and engineering, as well as technical expertise in areas such as fabrication, instrumentation and systems integration. Education and research training need to interact with specialist infrastructure, sustained research funding, knowledge transfer, standards, procurement and international co-operation.

The OECD's overview of national quantum strategies examines the timelines, motivations, scope, objectives, governance and assessment arrangements through which countries support the development and uptake of quantum technologies (OECD, 2025^[10]). It identifies a portfolio of commonly used instruments, including institutional funding for public research, competitive project grants, grants for business research and innovation, public procurement and equity finance. This shows that national capability is not pursued through education or workforce measures in isolation.

The strategies reviewed by the OECD combine scientific and technological objectives with economic, societal and, in some countries, security considerations. Public research funding and specialist infrastructure remain foundational, while support for business research, innovation and uptake becomes more prominent as applications develop. Governance arrangements are used to connect public research organisations, higher education institutions, businesses and government authorities, although their composition and authority vary among countries.

Several lessons follow for advanced STEM skills policy. First, the relevant competence is not confined to graduates from programmes bearing a quantum label. Research and innovation draw on deep disciplinary competence developed in established fields, combined with increasing opportunities for interdisciplinary specialisation. School education contributes broad mathematical, scientific and computing foundations. VET may develop enabling technical competence as applications and infrastructure mature. Bachelor's and master's programmes can combine solid disciplinary foundations with specialised options, while doctoral and postdoctoral training remain central to research capability. Continuing education can enable researchers and professionals from adjacent fields to develop additional competence where their existing foundations are relevant.

Second, education and research capacity cannot be separated. Increasing the number of specialised learners without educators, supervisors, research positions, infrastructure and viable career routes would provide a limited response. Access to research facilities and active research environments affects both the quality of training and the competence that learners can develop. The long time required to educate researchers and build specialist communities also means that capacity decisions need to extend beyond short-term demand signals.

Third, the skills question cannot be reduced to estimating a required number of graduates. National capability depends on the balance of disciplinary backgrounds, the interaction of research and technical roles, and movement between higher education, public research and industry. It also depends on whether organisations possess the infrastructure, complementary expertise and absorptive capacity required to use specialised competence. A strategy focussed only on education supply would overlook much of the system through which that competence produces scientific, economic or societal value.

Finally, quantum illustrates the need for periodic strategic review. The relative maturity of sensing, communication and computing applications differs, and future trajectories remain uncertain. Strategies need to support current research and capability while preserving the capacity to adjust priorities. Strong disciplinary foundations, interdisciplinary routes and mobility between research and professional settings can reduce the risks associated with dependence on a single technological forecast. The OECD's wider quantum work similarly emphasises anticipatory governance, international co-operation and the need to address the opportunities and risks of quantum technologies as they develop.

National quantum strategies thus demonstrate the advantages of field-specific co-ordination but also reinforce the two trade-offs identified at the beginning of this section. Specificity can direct attention to distinctive research and infrastructure needs, yet it should not become excessive dependence on uncertain forecasts. Political ambition can mobilise resources and institutions, yet its achievement depends on sustained teaching, research, infrastructure and supervisory capacity.

The formats of a strategy discussed above differ in scope, governance and degree of specialisation, but they face a common implementation challenge: translating strategic direction into priorities that address diagnosed constraints, assign clear responsibilities and are supported by sufficient capacity. This requires action across the policy portfolios and actors that shape how advanced STEM skills are developed, demonstrated, applied and renewed. The eight areas for policy action provide a framework for identifying and combining such action.

Eight areas for policy action to guide strategies for advanced STEM skills

The development and effective use of advanced STEM skills is a cross-portfolio policy concern. In many systems, responsibilities for higher education and for science, technology and innovation are distributed across different ministries, agencies or policy portfolios. Effective co-ordination can connect the higher education framework with the national science, technology and innovation ecosystem and strengthen coherence across the routes through which advanced STEM skills are developed, demonstrated, applied and renewed.

The eight areas for policy action translate this cross-portfolio perspective into strategic directions that countries can select, combine and adapt to their institutional arrangements, policy priorities and diagnosed constraints. They are intended to inform the design, implementation and evaluation of strategies for advanced STEM skills. Their application should account for differences in system size and capacity, including the particular challenges smaller higher education and research systems may face in sustaining specialised programmes and research capacity, attracting and retaining talent, and balancing national provision with cross-border collaboration.

Learning from existing practice can be an important element in this, provided that examples are interpreted in relation to the constraints, institutional arrangements and implementation capacity of each system. Table 3.2 summarises the principal approaches and examples discussed in Chapter 2 and shows how they relate to the eight areas.

Table 3.2. Eight areas for policy action: implementation approaches and examples

Area for policy action	Principal approaches discussed in Chapter 2
1. Enabling learners with the interest and potential to succeed to enter or return to high-quality STEM higher education	Strengthen mathematical, scientific and digital foundations; widen access to substantive STEM experiences; strengthen the relevance of STEM and learners' sense of belonging; improve information, guidance and transitions; and use diagnostic assessment, preparatory provision and other routes to support entry or return.
2. Making learning, persistence and completion central to the quality of STEM programmes while preserving academic standards	Diagnose differences in learning, persistence and completion; connect evidence with co-ordinated academic, practical and psychosocial support and institutional improvement; strengthen teaching, assessment, feedback, supervision and programme coherence; redesign first-year experiences and programme structures where required; enable flexible continuation, interruption and return; and address financial and other constraints on participation.
3. Establishing transparent and usable routes between levels, fields, employment and return	Strengthen recognition of prior learning, credit transfer and competence frameworks; establish transparent progression between qualification levels; enable movement across disciplines and fields; recognise relevant prior learning and experience; provide bridge, conversion and preparatory routes; and support movement between education, employment and return to study.
4. Widening equitable access to substantive research and professional experience	Embed research and professional experience within programmes; fund participation where unpaid or additional activity would restrict access; strengthen access to research environments, infrastructure, partnerships and mobility; connect doctoral education with cross-sector research and professional settings; and expand access to paid, substantive and appropriately supported professional experience.
5. Renewing programmes around profiles of disciplinary, interdisciplinary, transversal and professional competence	Define the competence profiles required in established and emerging fields; preserve strong disciplinary and methodological foundations; integrate interdisciplinary, transversal and professional competence; strengthen connections among STEM fields and with relevant non-STEM fields; involve external partners in programme design and delivery while preserving institutional responsibility for educational quality; and use evidence on technological, scientific, societal and professional developments to support continuing programme renewal.
6. Improving career entry and the effective use and continued development of advanced STEM skills	Build shared routes between higher education, research and employment; support entry into suitable first professional roles; improve employers' interpretation and recognition of advanced STEM skills; connect recruitment with effective onboarding, substantive work and continued development; strengthen work organisation and management practices that enable advanced STEM skills to be applied; and improve employment conditions, career development and advancement where these affect skills use and retention.
7. Building coherent routes for skills renewal across working life	Develop provision for updating and deepening existing competence, moving into adjacent fields and making more substantial professional transitions; enable adults to return to higher education through differentiated entry, recognition of prior learning, diagnostic assessment and bridge or refresher provision; support flexible participation; clarify the level, recognition and relationship of shorter learning to larger qualifications; and enable learning to accumulate into coherent and usable progression routes.
8. Building sustainable pedagogical, organisational and resource capacity in higher education institutions and strengthening their role in policy learning	Sustain qualified academic, technical, professional and support staff; strengthen curriculum design, teaching, assessment, feedback, supervision and programme leadership; develop connected learner support, recognition, interruption and re-entry arrangements; provide suitable teaching and research infrastructure and environments; strengthen institutional data, analytical and research capacity; support collaboration and shared provision where appropriate; secure sustainable finance and implementation time; and enable higher education institutions to contribute to monitoring, evaluation and continuing policy learning.

In the following, the eight areas for policy action are discussed in terms of their rationale, scope and implementation considerations.

Area for policy action 1. Enabling learners with the interest and potential to succeed to enter or return to high-quality STEM higher education

Advanced STEM skills cannot be developed across the broadest possible talent base when avoidable gaps in preparation, information, institutional capacity and accessible provision determine who can enter or return to STEM higher education.

Effective action requires clear roles across entry and re-entry routes. Public policy can address wider barriers relating to prior educational opportunities, finance, accessibility and location. Higher education policy can provide funding, admission, recognition, quality-assurance and information frameworks that

support entry and return. Higher education institutions remain responsible for admission and recognition decisions, preparatory provision, programme information, transition support, and the quality and capacity of provision. Schools, vocational providers, employers and other organisations can contribute preparation, guidance, occupational information, substantive STEM experiences and access to professional communities.

Policy monitoring should follow routes into higher education, including access to prerequisite subjects and the preparation they provide, participation in guidance and preparatory provision, application, admission, enrolment and initial progress. It should examine who benefits from these opportunities, where qualified and interested learners cease to progress, and whether interventions reduce or reproduce differences across population groups, institutions and locations.

Area for policy action 2. Making learning, persistence and completion central to the quality of STEM programmes, while preserving academic standards

Entry or return to higher education is only the first step. Learners must subsequently have a genuine opportunity to develop the intended advanced STEM skills and complete their programmes. Learning, persistence and completion should therefore be treated as central dimensions of programme quality, without lowering academic standards.

Constraints may arise at several levels. Individual-level constraints include gaps in preparation and financial or practical pressures. Programme-level constraints include weaknesses in curriculum design, teaching and assessment, limited practice and feedback, excessive workloads and weak belonging. Institutional-level constraints include inadequate learner support, inflexible study arrangements and insufficient programme leadership. These constraints may interact and be concentrated in particular courses, transitions or learner groups. They may be especially consequential in introductory and gateway courses during the early undergraduate years, where avoidable weaknesses in teaching, assessment and programme culture can lead to the loss of students who entered with strong academic preparation and the potential to succeed. Withdrawal, transfer, interruption or delayed completion does not by itself reveal the cause or indicate learner failure.

Effective action requires clear roles. Public policy can address financial, practical and accessibility barriers and ensure sufficient teaching and learner-support capacity. Higher education policy can reflect learning, persistence, completion and practical accessibility in funding and quality assurance. Higher education institutions remain responsible for curriculum, teaching, effective teaching, including appropriately designed active and interactive approaches, assessment, programme coherence, learner support, flexible continuation and programme culture. They also need the records, information systems, designated responsibilities and academic guidance required to preserve completed learning, maintain proportionate contact during interruption and support planned re-entry. Programme leaders play a central role and require appropriate authority, time, support and recognition.

Policy monitoring should examine learning and competence development, course performance, credit accumulation, workload, access to practical learning and support, transfer, interruption, re-entry, delayed completion and completion. A unique student identifier that remains with the learner across institutions, education sectors and periods of study can support secure linkage of enrolment, credit, transfer and completion records and help distinguish permanent withdrawal from transfer, interruption and later return. Its use requires consistent reporting, interoperable systems and clear safeguards governing access, linkage, privacy and permissible uses. Monitoring should identify where difficulties are concentrated, distinguish changes in educational route from displacement by avoidable barriers, and assess whether learners develop the intended disciplinary, interdisciplinary, transversal and professional competence.

Area for policy action 3. Establishing transparent and usable routes between levels, fields, employment and return

Formally available routes do not provide genuine opportunities when learners cannot understand their requirements, obtain recognition for relevant previous learning, or access the preparation and support needed to reach their intended destination. These routes include return after an interruption, re-entry after employment and entry to a different level or field for skills renewal.

Progression may be constrained by unclear admission requirements, inconsistent recognition of previous learning, unnecessary repetition, missing disciplinary or methodological foundations, limited bridge provision, unequal access to information and research experience, financial and geographical barriers, and selection points that learners could not reasonably anticipate. At advanced levels, limited funding, supervision and research infrastructure may restrict progression even where qualified and interested learners are available. Low immediate progression does not by itself indicate a barrier, since entry into suitable employment may be an informed and valuable outcome.

Making progression routes usable requires connected responsibilities. Public policy can support coherent qualification frameworks and address financial, geographical and administrative barriers across education, research and employment. Higher education policy can establish admission, credit, recognition and funding frameworks that support movement between institutions, levels and fields. Higher education institutions remain responsible for admission and recognition decisions, transparent programme requirements, curriculum mapping, bridge provision and ensuring that learners admitted through different routes possess or can develop the necessary foundations. Institutions also need sufficient organisational capacity to retrieve and interpret previous records, provide timely recognition decisions and develop an individual route connecting previous learning with current programme requirements. Vocational providers, research organisations, employers, professional bodies and qualification authorities can help connect educational and occupational routes and clarify their requirements.

Policy monitoring should follow application, admission and recognition decisions, recognised credit, additional preparation, progression, remaining duration and cost, completion and subsequent education or employment. Where learners move between institutions or return after an interruption, linked longitudinal records can show whether previous learning is preserved and whether formal re-entry leads to continued progression and completion. Monitoring should distinguish voluntary entry into employment from progression prevented by avoidable barriers and assess whether formal progression rights translate into usable routes across institutions, fields, educational backgrounds and learner groups.

Area for policy action 4. Widening equitable access to substantive research and professional experience

Research and professional experience help learners develop advanced STEM skills and provide evidence that institutions and employers use when assessing readiness for further study and work. Unequal access can therefore affect persistence, progression and career entry.

Access may be constrained by unpaid or poorly paid participation, informal selection and networks, institutional prestige, geographical mobility, additional accommodation, transport and care costs, and limited availability of suitable opportunities. Experiences may also provide little educational value where learners receive routine or peripheral tasks, insufficient supervision or feedback, or few opportunities to connect experience with academic learning. Participation alone does not establish that advanced STEM skills have been developed.

Research and professional experience may also depend on access to research environments, specialist facilities, data, equipment and complementary expertise that individual institutions or employers cannot provide alone. Shared facilities, collaborative research environments and partnerships among higher

education institutions, research organisations, employers and public bodies can widen access, particularly for learners and organisations in less research-intensive institutions or regions. Such arrangements should define responsibilities for access, supervision, safety, intellectual property, data use, assessment and recognition and should ensure that participants undertake substantive work rather than observe or provide routine assistance.

Higher education institutions remain responsible for transparent selection, academic oversight, learning objectives, assessment and connections with the curriculum. Research organisations and employers are responsible for substantive tasks, prepared supervisors, appropriate feedback, accessible working environments and opportunities to exercise technical and professional judgement. Where specialist capacity is distributed across organisations, public authorities, funders and intermediary organisations can support shared facilities, collaborative research environments and access arrangements that enable learners and early-career professionals to participate in substantive research and innovation activity.

Policy monitoring should examine who benefits; how participants are selected; whether participation is financially and practically feasible; the tasks and responsibilities assigned; and the quality of supervision and feedback. It should also follow subsequent progression into further study or suitable employment and assess whether the learning and evidence produced remain portable beyond the participating institution, employer or sector.

Area for policy action 5. Renewing programmes around profiles of disciplinary, interdisciplinary, transversal and professional competence

Advanced STEM education must respond to changes in knowledge, technology and professional practice while preserving the durable foundations needed for future learning and responsible application.

Programme renewal may be constrained by unclear learning outcomes, weak connections among courses, insufficient assessment of intended competence, superficial integration across disciplines, limited professional and societal application, and curricula organised around short-lived tools or immediate employer requirements. Programme titles and competence frameworks may not reveal the depth of disciplinary learning, the form of integration achieved or the educational and occupational routes supported. Adopting a competence profile does not by itself establish that the intended learning is developed or assessed.

Programme renewal is principally an institutional responsibility, supported by appropriate public frameworks and informed by other actors. Public policy can support national or sectoral competence frameworks, skills intelligence and collaboration where common terminology and shared evidence provide wider benefits. Higher education policy can provide funding, quality-assurance expectations and educational-development capacity while preserving institutional responsibility for academic standards. Higher education institutions remain responsible for curriculum, teaching, assessment and the coherence of disciplinary, interdisciplinary, transversal and professional competence. Educators and programme leaders translate competence profiles into sequenced learning and credible assessment. Employers, professional bodies, research organisations and societal partners can clarify changing problems, tasks and contexts, but should not narrow programmes around the immediate requirements of particular technologies, occupations or organisations.

Skills intelligence can identify changes in occupations, tasks, technologies and competence requirements and help institutions assess the need for adaptation, new provision or collaboration. It should remain one input to institutional judgement, not a direct curriculum specification. Available evidence may reflect broad categories, stated recruitment requirements, temporary or local demand, and employer recruitment practices rather than the advanced STEM skills actually needed and used. Institutions should interpret it in light of programme purpose, level, disciplinary foundations and intended destinations, distinguishing

needs for programme renewal from optional specialisation, continuing education, work-based learning or employer-provided onboarding.

Policy monitoring should examine whether competence profiles and relevant evidence are translated into coherent curricula, teaching, substantive learning opportunities and credible assessment. It should assess whether learners develop durable disciplinary and methodological foundations, whether interdisciplinary provision achieves genuine integration, and whether learners can communicate, demonstrate and apply their competence in further education, research and employment.

Area for policy action 6. Improving career entry and the effective use and continued development of advanced STEM skills

Developing advanced STEM skills will produce limited economic and societal value if individuals cannot obtain suitable work or if employers cannot recognise, use and continue developing the competence available.

Career entry and effective skills use may be constrained on both the individual and employer sides. Individual-facing constraints include unequal access to professional experience, occupational information and professional networks, as well as financial, geographical and personal barriers to suitable work. Employer-side constraints include difficulty interpreting and validating advanced STEM skills, narrow recruitment criteria, demands for directly comparable experience or organisation-specific knowledge, insufficient onboarding, restricted task allocation, limited autonomy and feedback, weak development opportunities, and working conditions or advancement structures that undermine progression and retention. Recruitment difficulty does not by itself establish that relevant advanced STEM skills are unavailable.

Employers remain primarily responsible for recruitment, onboarding, task allocation, work organisation, working conditions and continued development. Their involvement during education can improve routes into STEM careers, but does not substitute for realistic entry requirements, effective onboarding or opportunities to use and further develop advanced STEM skills after recruitment. Employer organisations, professional bodies and intermediaries can provide shared information, frameworks and support, particularly for employers with limited internal capacity.

Effective use also depends on whether organisations have suitable demand and application capacity. Employing people with advanced STEM skills will have limited effects where organisations lack research and innovation activity, access to appropriate technologies and infrastructure, complementary technical and managerial expertise, or the organisational capacity to define substantive problems and incorporate specialist evidence into decisions. These constraints may be particularly important for SMEs and public organisations that cannot maintain extensive internal research, technical or innovation functions.

Responsibilities differ across actors. Public policy can address wider barriers to suitable work and retention. Higher education policy and institutions can make assessed advanced STEM skills clearer, provide career guidance and connect learners with substantive professional experience. Employers can contribute to the planning, co-design and delivery of STEM programmes by identifying durable changes in professional practice, contributing authentic problems and specialist expertise, and providing funding, traineeships, internships, placements and other forms of work-based learning. Such involvement can strengthen the relevance of programmes and help learners develop, apply and demonstrate advanced STEM skills in professional settings. Higher education institutions nevertheless remain responsible for curriculum coherence, assessment, academic independence and qualification standards (see Area for policy action 5).

Research, innovation, industrial, regional and public-sector policy can complement these education–employer connections by strengthening the environments in which advanced STEM skills are applied. Depending on the diagnosed constraint, relevant instruments may include research and innovation

funding, technology-diffusion and extension services, access to shared laboratories, testing facilities, data and computing infrastructure, collaborative research and demonstration projects, and innovation-oriented public procurement. Support for management and organisational development can help organisations identify suitable applications, integrate new technologies with existing processes, establish multidisciplinary teams and give technical expertise an effective role in organisational decisions.

For SMEs and public organisations with limited internal capacity, intermediary and shared arrangements may be especially important. Higher education institutions, public research organisations, technology centres, professional bodies and regional innovation organisations can provide access to facilities, specialist advice, collaborative research and professional networks that individual organisations could not sustain alone. Public support should strengthen organisations' capacity to undertake research, adopt and adapt technologies and use advanced STEM skills, rather than subsidise isolated recruitment without the infrastructure, complementary expertise or organisational changes needed for effective application.

Policy monitoring should follow individuals beyond initial employment and examine access to suitable roles, recruitment outcomes, onboarding, actual skills use, task complexity, autonomy, professional judgement, feedback, continued development, advancement, working conditions and retention. It should also examine whether organisations increase their capacity to undertake research, adopt or adapt technologies, access suitable infrastructure and complementary expertise, and organise work so that advanced STEM skills influence products, services, processes and decisions. For publicly supported measures, monitoring should establish whether organisations develop lasting internal or shared capacity, whether benefits extend beyond a single recruitment episode, and whether effects differ by organisational size, sector and location.

Area for policy action 7. Building coherent routes for skills renewal across working life

Changes in knowledge, technology and work create learning needs throughout working life that cannot be met through initial education or disconnected short courses alone. Skills renewal may be constrained by provision that is unavailable, fragmented, difficult to navigate or poorly recognised; unclear prerequisites and learning outcomes; missing foundations; inconsistent recognition of previous learning; unsuitable cost, scheduling or delivery; limited employer support; insufficient access to specialist educators, infrastructure and learner services; and few opportunities to apply the competence developed.

Effective action for skills renewal requires clear roles and coherent routes. Public and higher education policy can provide finance, information, quality-assurance and recognition frameworks. Higher education institutions remain responsible for accessible entry, recognition, coherent provision and credible assessment, while employers should enable participation and opportunities to apply the competence developed. Institutions also need the organisational capacity to support people returning after employment, interruption or a longer absence. This includes accessible information and guidance, reliable records of previous learning, timely recognition decisions, diagnostic assessment, bridge or refresher provision and clearly assigned responsibility for helping learners identify an appropriate route.

Based Routes should clarify prerequisites, learning outcomes, assessment, recognition and further opportunities, with diagnostic assessment and bridge provision addressing essential gaps. Flexible provision should retain access to the educators, infrastructure, practical learning and support required for advanced learning. Professional bodies and other providers can meet specialised needs, while higher education has a distinctive role where skills renewal requires advanced disciplinary and methodological learning, research-informed content, specialist infrastructure or a recognised qualification. Short courses and micro-credentials may support focussed learning or contribute to larger routes but should not substitute for missing foundations or the coherent learning required for substantial occupational change.

Policy monitoring should extend beyond enrolment and completion to the competence developed, the credibility and portability of recognition, application in work or further education, progression towards the

intended destination and longer-term employment outcomes. It should examine who participates and benefits, who receives employer support, whether short courses and micro-credentials form coherent routes where accumulation is intended, and whether learners can understand likely recognition and progression outcomes before committing substantial time and resources. It should also examine whether returning learners receive timely recognition and guidance, whether previous learning is preserved where it remains relevant, whether identified gaps are addressed through proportionate preparation and whether learners continue towards their intended educational or occupational destination.

Area for policy action 8. Building sustainable pedagogical, organisational and resource capacity in higher education institutions, and strengthen their role in policy learning

Higher education institutions need sustainable capacity not only to expand provision, but also to maintain its quality, support different educational routes, provide substantive practical and research learning, renew programmes and respond to skills-renewal needs.

Pedagogical capacity includes sufficient qualified educators, supervisors and technical staff, with adequate time and support to develop and use effective teaching approaches, including active and interactive pedagogy, and to undertake assessment, supervision, curriculum development and educational improvement. Organisational capacity includes effective programme leadership, manageable workloads, co-ordination across courses and organisational units, functioning learner-support arrangements, recognition and guidance for returning learners, processes for interruption and planned re-entry, and the capacity to collect, connect and use data on learning, progression, competence development and outcomes. Resource capacity includes stable and sustained finance, specialist facilities, laboratories, equipment, digital environments, data systems and access to suitable research and professional settings. Where learners transfer, interrupt or return after several years, compatible records and, where permitted, a unique student identifier can support continuity across institutions, education sectors and periods of study. These forms of capacity may differ across fields, qualification levels, institutions and locations.

Building sustainable capacity requires co-ordinated action and continuing capacity building. Public policy can align ambitions for advanced STEM skills with decisions on education, research, infrastructure, regional development and public finance. Higher education policy can provide sustained funding, quality-assurance and data frameworks that reflect the differing costs and requirements of high-quality STEM provision. Higher education institutions remain responsible for staffing, workload management, infrastructure, programme leadership, organisational co-ordination, learner support, data governance and the quality of provision. Research organisations, employers and other partners can contribute specialist expertise, facilities, data and professional environments, with clear responsibilities for teaching, supervision, assessment, accessibility, support and appropriate data use.

Capacity-building measures should strengthen educators, supervisors, technical staff, programme leaders and institutional teams, rather than focus only on additional places or infrastructure. Collaboration across higher education institutions can support shared provision and facilities, exchange effective approaches, develop common evidence and extend access to specialised expertise. Such collaboration should support mutual learning while preserving institutional responsibility for academic standards, programme quality and learner support.

Policy monitoring should examine staffing, workloads, educator and supervisor development, infrastructure, programme leadership, learner support, organisational co-ordination, data capacity, and the sustainability and geographical distribution of resources. It should assess whether institutions can support high-quality learning, progression, substantive research and professional experience, programme renewal and skills renewal, and whether learners can access this capacity in practice.

Higher education institutions have a core role in policy learning because they generate and interpret evidence on implementation, learning and outcomes and can identify how common policies operate across

fields, programmes and learner groups. Monitoring arrangements should support institutional improvement, capacity building and structured learning across institutions and between institutions and policymakers, rather than serve only reporting and accountability purposes. Where provision expands, monitoring should establish whether constraints are resolved or transferred to later stages.

Conclusion

An effective strategy for advanced STEM skills begins with a sufficiently specific diagnosis. It should connect the development, recognition, effective use and renewal of advanced STEM skills rather than address individual educational or employment outcomes in isolation. Strategies may be dedicated to STEM, incorporated into broader education, skills, research, innovation or industrial strategies, or focused on a particular field or technology. Their value depends less on their formal designation than on whether they connect responsibilities and interventions around shared priorities and diagnosed constraints.

International mobility and collaboration should form part of this strategic perspective, connecting the attraction of learners, researchers and professionals with the recognition of qualifications and experience, integration into education, research, employment and wider society, suitable conditions for retention and continued development, opportunities for return and collaboration, and consideration of effects on origin and destination countries. A strategic focus on advanced STEM skills does not imply prioritising STEM over non-STEM fields. Sustainable growth and responsible innovation depend on contributions from both and on their effective integration. Attention to career entry and effective skills use also moves the discussion beyond the number of STEM graduates produced to whether their competence is recognised, applied and continually developed at work.

System size and capacity affect how a strategy can be implemented. Smaller higher education and research systems may face particular challenges in sustaining specialised programmes and infrastructure, maintaining research capacity, attracting and retaining talent, and providing opportunities across all fields nationally. Shared provision, access to cross-border infrastructure, institutional collaboration, mobility and international research and education partnerships can complement national capacity. Such arrangements should preserve clear responsibilities for academic quality, recognition, learner support, supervision and the continuity of educational routes.

The eight areas for policy action are intended to inform the design, implementation and evaluation of strategies for advanced STEM skills and support co-ordinated action across policy portfolios. They are strategic directions that countries and other actors can select, combine and adapt to their diagnosed constraints, institutional arrangements, implementation capacity and policy priorities, rather than a standard set of measures for every system. Under conditions of technological and labour market uncertainty, their application should combine continuity in the development of durable foundations and long-term capacity with the ability to review and adjust priorities as evidence, technologies and competence requirements develop.

Higher education institutions are strategic partners in implementing these directions and supporting policy learning. Their contribution depends on sustainable pedagogical, organisational and resource capacity, including qualified academic and technical staff, programme leadership, learner support, specialist infrastructure, research environments, staff time, stable finance, and the data and analytical capacity required for institutional improvement and policy learning.

Ultimately, the effectiveness of a strategy should be assessed by whether people from a sufficiently broad talent base can develop advanced STEM skills, whether those skills are recognised and used effectively, and whether they can continue to develop and be renewed across working life.

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Annex A. Mutual Learning Group on Advanced STEM Skills in Higher Education

Purpose and contribution to the report

The Mutual Learning Group (MLG) on Advanced STEM Skills in Higher Education was organised by the OECD Secretariat as part of the project “Supporting effective implementation of the STEM Education Strategic Plan: the promotion of STEM in higher education”, undertaken with financial support from the European Union’s Erasmus+ programme. It brought together policymakers, researchers, higher education practitioners and other experts to discuss the development, effective use and renewal of advanced STEM skills.

The group provided a forum for countries and jurisdictions to identify, share and examine policies and practices through structured exchange and evidence-informed dialogue. Its scope included system-level strategies and co-ordination mechanisms, curriculum and programme reforms, funding and regulatory incentives, entry and progression in STEM higher education, transitions into employment, and routes for skills renewal across working life.

The Mutual Learning Group also provided a lens through which the literature, comparative data and policy analysis used in this report could be read and interpreted for their policy relevance, implementation requirements and applicability across contexts. Quantitative evidence helped identify patterns and differences across countries, fields and population groups, while the research literature provided evidence on the mechanisms that might produce them. Discussion in the group helped relate this evidence to the operation of education systems, higher education institutions, employers and public authorities in different contexts.

Bringing these sources together contributed to the structure of the report’s analytical framework. The discussions helped identify commonalities across countries while distinguishing context-specific causes, test the relationships among bottlenecks, policy priorities and areas for policy action.

Composition of the group

The group brought together policymakers, researchers, higher education practitioners and other experts with experience from Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Denmark, Estonia, Finland, Germany, Ireland, Japan, Korea, Poland, Portugal, Spain and Trinidad and Tobago. It also included participants from the European Commission’s Joint Research Centre, UNESCO and other relevant organisations.

Members were selected to bring together complementary knowledge of the issues covered by the project. Their experience included:

- national and regional policy and system co-ordination
- higher education and research policy
- programme and institutional development

- teaching, learning and learner support
- STEM participation and inclusion
- progression to advanced study and research
- emerging scientific and technological fields
- transitions between education and employment
- skills renewal across working life

The participating countries and organisations provided experience from different education systems, policy arrangements, institutional structures and economic contexts. This enabled the group to discuss both system-level frameworks and the conditions under which policies and practices operate within higher education institutions and other organisations.

The group was constituted to support comparative policy learning. Several participants were associated with the same country where they contributed different forms of policy, research, institutional or practical knowledge.

Members participated in their individual capacity. They contributed their personal expertise and experience and did not formally represent the views or positions of the organisations with which they were professionally affiliated.

List of members of the Mutual Learning Group (sorted in alphabetical order by last name)

Guia Bianchi (European Commission Joint Research Centre); Joscha Dapper (Ministry of Science, Research and Culture of Brandenburg, Germany); Eva Diaz (STEM Women Spain, Spain); Kaori Furuya (Ministry of Education, Culture, Sports, Science and Technology, Japan); Bárbara Gabriel (University of Aveiro, Portugal); Franziska Greinert (Quantum Valley Lower Saxony, Germany); Karel Hageman (European Commission Joint Research Centre); Tomi Halonen (Ministry of Education and Culture, Department for Higher Education and Science Policy, Finland); Jan Hesselbarth (German Council of University Faculties in Engineering and Informatics, Germany); Michael Hoch (KIT - Karlsruhe Institute for Technology/ Germany - European Organization for Nuclear Research, CERN); Val Ianniti (Actua, Canada); Roman Jurowetzki (National Centre for Artificial Intelligence in Society, Denmark); Jan Lundell (LUMA Centre Finland, Finland); Maria Manatos (Agency for Assessment and Accreditation of Higher Education, Portugal); Loredana Maravić (Ministry of Science, Education and Youth, Croatia); Nikki Meller (Women in AI Australia, Australia); Jeehye Min (Science and Technology Policy Institute, Korea); Tatrik Merlin (Education and Youth Board, Estonia); Ruaidhri Neavyn (Higher Education Authority, Ireland); Maarit Palonen (Ministry of Education and Culture, Department for Higher Education and Science Policy, Finland); Kristi Raudmäe (Ministry of Education and Research, Estonia); Ivana Radonova (Ministry of Education and Science, Bulgaria); Tracey Ross (Actua, Canada); Elisabeth Roth (Federal Ministry for Women, Science and Research, Austria); Manuel Sánchez-Masferrer (Global University Network for Innovation / United Nations Educational, Scientific and Cultural Organisation); Bianka Siwinska (Perspektywy Education Foundation and Perspektywy Women in Tech, Poland); Noah Sobe (Global University Network for Innovation / United Nations Educational, Scientific and Cultural Organisation); Andrzej Stolarczyk (Ministry of Science and Higher Education, Poland); Laura Taajamaa (Ministry of Education and Culture, Department for Higher Education and Science Policy, Finland); Marjo Vesalainen (Ministry of Education and Culture, Department for Higher Education and Science Policy, Finland); and Provincial and territorial governments under the aegis of the Council of Ministers of Education, Canada.

Meetings and working method

The Mutual Learning Group met online four times between April and July 2026, with preparation and follow-up exchanges before and after the meetings. The first meeting introduced the project, discussed its scope and initial analytical framework, and identified significant policy challenges and relevant policy or institutional initiatives. The following three meetings examined selected policies and practices in greater depth.

Members discussed and agreed on a common analytical framework during the first meeting. The framework structured the preparation of presentations and supporting material and provided a common basis for discussion. It remained open to refinement as the work progressed, allowing findings from successive meetings to contribute to cumulative analysis.

Dimension	Criteria
1. Rationale for the policy/practice and context	<ul style="list-style-type: none"> • Clear problem definition (skills gaps, shortages, mismatch, equity gaps, innovation needs) • Scope and level (regional/national; discipline focus; level of study) • Fit with broader policy mix (immigration, labour, R&D, industrial policy, procurement) • Evidence on demand and use of advanced STEM skills • Clear identification of target sectors, occupations and intended beneficiaries
2. Role of public policy	<ul style="list-style-type: none"> • Clarity of public policy priorities for advanced STEM skills development • Role of intermediary bodies • Autonomy and flexibility granted to HEIs, including policy steering • Stability of public policy commitments • Co-ordination across key policy stakeholders (e.g. education, research, industry, finance)
3. Resources	<ul style="list-style-type: none"> • Predictability and duration of funding • Human resources, including capacity, training, incentives and technology-enabled teaching support • Student financial support mechanisms • Availability of specialised laboratories, equipment, computing capacity and software • Networked resources and critical mass across institutions and partners
4. Governance, monitoring and evaluation	<ul style="list-style-type: none"> • Clear roles and responsibilities • Data systems tracking student progression, employment and research outputs • Rules for scaling, redesigning or ending initiatives • Sufficiently granular metrics and capacity to develop, analyse and use data • Evaluation, quality assurance and adaptability supporting continuous improvement
5. Impact and scalability	<ul style="list-style-type: none"> • Transferability across institutional types or regions • Long-term sustainability and equity of impacts • Evidence of graduate employment, progression and other outcomes • Contribution to innovation, productivity and knowledge creation, adapting to technological and labour market change • Scalability and capacity building across the education and lifelong-learning continuum

For meetings two to four, members prepared concise presentations and, where appropriate, supporting material on selected policies or institutional practices. Presentations addressed the initiative's rationale and context, the role of public policy, required resources, governance, monitoring and evaluation, and available evidence on its effects and wider applicability.

Presentations were followed by plenary questions examining the initiative's scope, the actors involved, implementation arrangements and the available evidence. Breakout discussions compared initiatives around two recurring questions: whether existing rules, incentives and capacity enabled higher education institutions and their partners to act; and which conditions and mechanisms enabled policies and institutional practices to improve, adapt and expand over time.

The discussions identified what supported implementation, what remained constrained or fragile, and which policy levers could address the limitations identified. This structure moved the exchange from descriptions of individual initiatives towards comparative policy learning while preserving differences among systems and settings.

Policies for Developing Advanced STEM Skills in Higher Education

Advanced STEM skills are essential for the responsible use of technology. This report defines them as disciplinary, interdisciplinary, transversal and professional competence applied to complex scientific and technological problems and responsible innovation, with ethical, societal and environmental implications. Quantum technologies and artificial intelligence illustrate fields requiring advanced STEM skills, yet determining whether skills for these and other fields are in short supply is difficult. The report identifies five bottlenecks: entry into STEM higher education; persistence and completion; progression to advanced levels; career entry and effective skills use; and skills renewal across working life. Building on this framework, four policy priorities address entry, persistence and completion; progression and skills renewal; programme renewal; and career entry and the effective use and continued development of advanced STEM skills. Policy and practice examples were analysed through the OECD Mutual Learning Group on Advanced STEM Skills in Higher Education, involving researchers, policymakers and higher education practitioners from a wide range of countries. The report's eight recommendations propose options to address constraints at individual, institutional, employer and system levels, highlighting that implementation requires collaboration across policy portfolios. The report offers a framework for strengthening the development and use of advanced STEM skills and supports implementation of the European Union's STEM Education Strategic Plan: Skills for Competitiveness and Innovation.



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