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SCIENCE FOR POLICY BRIEF

# STEM and STEAM education, and disciplinary integration: a guide to informed policy action

## HIGHLIGHTS

→ Science, Technology, Engineering, and Mathematics (STEM) education is frequently associated with teaching and learning in core STEM disciplines, but their interconnection should be further explored by policy initiatives.

→ STEM teaching and learning evolved into integrated, student-centred approaches – commonly known as integrated STEM – that provide individuals with adequate competencies to address real-world problems.

→ Building on the latter, STEAM or STE(A)M education incorporates the arts, psychology, social sciences and humanities (SSH), and other disciplines, highlighting the importance of transversal skills such as adaptability, creativity, and problem-solving.

→ Integrated STEM and STEAM/STE(A)M require sufficient resources to adapt current education systems to innovative learning methods through effective curriculum design, educators' professional development, and modern infrastructure.

→ Integrated approaches to STEM empower learners to thrive in a fast-changing world while fostering democratic societies, innovation, and competitiveness.

→ However, there is no one-size-fits-all solution; multifaceted, context-based actions must acknowledge the complexity of educational inequalities, including gender and diversity gaps, to enhance engagement in STEM in the EU and bridge the skills gap.

→ Establishing comprehensive EU-wide STEM competence frameworks for learners and educators can enhance the potential of STEM education by consolidating definitions and concepts, defining learning outcomes, and identifying good practices across all educational levels, starting from early ages.

→ Establishing monitoring and evaluation frameworks for STEM initiatives is essential to assess the effectiveness of teaching methods and their impact on learning outcomes.

## INTRODUCTION

In the 1990s, the STEM education concept was formalised as a pragmatic response to emerging workforce needs, particularly in the United States. Since then, STEM education has been associated with technological advancements and having a competitive position in the global market.[1]

As we progress through the 21st century, various factors have reshaped the meaning of STEM and its educational approaches. Living in an increasingly dynamic and uncertain world requires a broader set of key competencies, i.e., the knowledge, skills, and attitudes for personal fulfilment and development, employability, social inclusion, and active and responsible citizenship. In addition, transversal skills are indispensable to keep pace with rapidly evolving technology and labour market needs.

In the last decade, the European Union (EU) has promoted several initiatives to strengthen key competencies. The 2018 Council Recommendation on key competencies for lifelong learning highlights the relevance of STEM, digital, literacy, multilingualism, entrepreneurship, cultural expression and awareness, citizenship competencies, among others.[2] In 2021, building on the Recommendation, Member States committed to having no more than 15% of 15-year-olds below a minimum competence level in basic skills by 2030.[3]

However, recent evidence reveals a significant and growing deviation from this target. Data from the 2022 OECD's Programme for International Student Assessment (PISA) shows that some 30% of 15-year-olds failed to reach the minimum proficiency level in mathematics and 25% in reading and science.[4] Data from the 2023 International Computer and Information Literacy Study (ICILS) shows that 43% of secondary students do not have a basic level of digital skills.[5]

Recently, STEM education has gained renewed attention in the European policy arena. The Draghi report underlined the need for further investment in STEM education to stimulate innovation,[6] and President von der Leyen set up lifelong learning and skills development as priorities for 2024-2029.[7] Building on this, in March 2025, the European Commission adopted the Union of Skills initiative[8] and the STEM Education Strategic Plan[9] to improve people's careers and prospects while boosting European competitiveness.

While STEM has become a key topic in policy agendas, this concept is surrounded by controversies with practical implications for developing adequate curricula and teaching approaches to foster students' STEM competencies.[10] Thus, this brief summarises and clarifies important concepts on STEM education and teaching approaches, building on a recent JRC literature review[11] and stakeholder exchanges. While we do not advocate adopting one type of STEM education or approach, we hope this brief can serve as a practical guide to future policymaking initiatives in this field.

## CONCEPTUALISING STEM

Over the years, the original STEM education concept, narrowly interpreted as concerning its core disciplines only, has evolved significantly. More elaborated interpretations, such as integrated STEM, STEAM or STE(A)M, came forward in response to real-world challenges. These will be discussed next.

### STEM education

STEM education is frequently associated with the core disciplines of science, technology, engineering, and mathematics, which support and enhance each other. Science gives the theoretical foundation, technology puts the theory into practice, engineering is the means to developing solutions, and mathematics contributes with the analytical and design tools to problem-solving. When combined, these disciplines create a unified, dynamic educational framework equipping students with competencies to engage with and contribute to a complex world.

However, currently, researchers and practitioners have no consensus on which disciplines constitute STEM and what makes up a desirable cohesive learning experience. In primary education, STEM is less concerned with an in-depth exploration of each subject and more with building essential skills such as problem-solving, critical thinking, and teamwork for later specialised learning.

In secondary education, STEM education typically includes mandatory courses in science and mathematics and optional courses such as computer science and engineering. In upper-secondary vocational education and training, technology and engineering courses are often offered to prepare students for specific STEM careers.

The specialisation trend peaks in higher education. In the first years of studies, disciplines are hyper-disaggregated, and programmes may be classified as STEM. In most cases, STEM is defined as a discipline or programme in biology, chemistry, physics, mathematics, engineering and, eventually, information and computer sciences (ICT).[11] Depending on employment and societal needs, the definition of core STEM education evolves and may even encompass the social sciences and/or psychology.

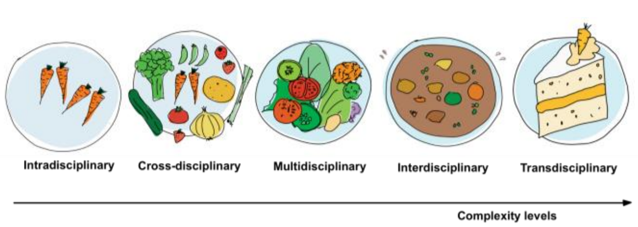
## Integrated STEM education

Over the past 20 years, disciplinary integration has emerged as the predominant characteristic of STEM. Integrated STEM education advocates teaching disciplines as interconnected fields, reflecting the complexity of real-world issues, rather than isolated subjects. Thus, individuals are empowered to apply knowledge holistically and understand how STEM disciplines are embedded in a broader societal context.

A key aspect of integrated STEM education is the focus on transversal skills, also referred to as 21st-century skills. These include adaptability, creativity, problem-solving, cross-disciplinary thinking, and continuous learning. These are stimulated by bridging the gap between the theoretical framework of core STEM disciplines and their real-word application, while accommodating the unique characteristics of each discipline.[12] Innovative teaching strategies and curricula can contribute to this goal, providing students with a cohesive learning experience. Additionally, non-formal and informal learning settings spark students' curiosity and enhance problem-solving skills through hands-on activities.

Implementing integrated STEM education requires that policymakers and educators choose the most suitable level of disciplinary integration along with the corresponding teaching methods for a specific context. However, before delving into this, we must first comprehend typical levels of disciplinary integration (see Figure 1).

**Figure 1** – Disciplinary integration levels




*Source:* Jo Bailey (2021).

The *intradisciplinary* approach studies a topic within the same discipline, in isolation from others. The *cross-disciplinary* approach proposes to view one discipline from the perspective of another. The *multidisciplinary* approach combines multiple disciplines, each contributing different insights. *Interdisciplinary approach* integrates knowledge and methods from multiple disciplines, developing interrelationships that encourage combined thinking towards new solutions to complex phenomena. The highest level of integration is *transdisciplinary*, which extrapolates disciplinary boundaries to create a "unity of intellectual frameworks" through co-creation between multiple actors (e.g., students, academics, companies, and civil society organisations).[13,14]

Some educators, educational researchers, and policymakers advocate for developing STEM education primarily from a multidisciplinary approach. They strongly believe in reinforcing foundational knowledge and skills within STEM disciplines.[11] Meanwhile, others promote teaching strategies and curriculum development that can support foundational competencies in each discipline while nurturing interdisciplinary learning at the same time.

In integrated STEM, the degree of disciplinary integration varies across education levels. In primary education, disciplines are commonly integrated, while secondary education is typically associated with more specialisation and less integration. Overall, educational systems aligned with integrated STEM commonly adopt multi-, inter-, and transdisciplinary approaches to teaching.[11,15]

However, evidence from 2022 shows an increase in separate-subject science teaching across Europe compared to a decade ago.[16] Abandoning the integrated science teaching practices previously adopted by some countries in compulsory education, most European curricula in lower secondary education prescribe the teaching of separate science subjects such as biology, physics, and chemistry.

Correlated and broad fields curricula effectively incorporate integrated STEM education.[17]
The *correlated curriculum* requires minimal adaptation from traditional programmes. Concepts should be applied timely and relevantly while promoting collaboration across disciplines without merging them, which may significantly impact subjects like algebra to align with physics, for example. However, it does not fully address skill development or technological competencies. The *broad fields curriculum* integrates related subjects into a cohesive framework centred on science, technology, and arts. The challenge lies in creating a structure that retains core elements while enhancing interdisciplinary learning. For instance, building and programming a robot helps students apply knowledge to solve real problems while relying on core STEM skills.

### STEAM or STE(A)M education

Some educators and researchers defend that complex problems are deeply linked to social and ethical contexts, requiring broader perspectives of other disciplines to tackle real-world challenges and enhance society.[18] This is how STEAM or STE(A)M education approaches arise; however, there is a lack of clarity regarding their terminology and pedagogical methods.[19,20,21]

STEAM education is often understood as STEM plus the arts. Some academics associate it with visual arts (painting, sculpture, and photography), while others adopt a broader definition encompassing performing arts, crafts, and expressive disciplines. In contrast, some advocate for integrating the liberal arts, social sciences, and humanities (SSH), along with other fields, into core STEM disciplines. To mark the integration of “all other subjects” into the STEM education framework, some stakeholders use the acronym STE(A)M education.[22,23] Common integration methods used in STEAM or STE(A)M teaching are cross-, multi-, inter-, and transdisciplinary approaches.[24]

## PRINCIPLES OF INTEGRATED STEM, STEAM OR STE(A)M EDUCATION

Building on literature reviews published in the last ten years, we can draw five principles underpinning integrated STEM, STEAM or STE(A)M education in secondary education.[11,25]

First, integration is fundamental. Learning objectives, content, and practices should be incorporated across core STEM disciplines and other fields.

Second, *problem-centred learning* engages students in authentic, complex, real-world problems. By fostering 21st-century skills such as critical thinking and problem-solving, students learn to apply theoretical knowledge to empirical situations.

Third, *inquiry-based learning* creates environments stimulating students' curiosity and encouraging their learning through experiences and hands-on activities.

Fourth, *design-based learning* is a type of inquiry-based learning. It poses open-ended design challenges to students, introducing them to engineering design processes and design-thinking practices to deepen their understanding of core disciplinary knowledge.

Fifth, *cooperative learning* stimulates communication and collaboration among students, enhancing their learning experience and transversal skills through structured teamwork and collaborative knowledge building.

These principles call for innovative pedagogical approaches at all educational stages, starting from primary education, to equip learners with essential tools for future studies. Active learning strategies centred on students include project-, problem-, and phenomenon-based learning.[26]

*Project-based learning* involves students engaging in projects that address real-world problems. These require interdisciplinary knowledge and collaboration to devise effective solutions, emphasising the practical application of STEM concepts in tangible scenarios.

*Problem-based learning* focuses on solving complex challenges. It encourages inquiry-driven, problem-solving skills and critical thinking by applying theoretical knowledge to practical situations. This approach is part of the overarching principle of problem-centred learning.

*Phenomenon-based learning* starts with observing a phenomenon, which could be anything interesting and complex enough to study further. This method promotes curiosity and encourages an inquiry-based approach to learning, where students synthesise information from various sources to understand complex subjects comprehensively.

## CONCLUSIONS

Integrated STEM education, including STEAM or STE(A)M, empowers students. By enhancing their agency and self-efficacy, students can see themselves as capable learners who can shape their educational journeys and contribute to society. These ecosystems cultivate a more knowledgeable, engaged, resilient, and democratic society, stimulating economic growth and innovation while building a skilled workforce in vital sectors.

While STEM education is emphasised in policy debates, various challenges hinder its successful application within educational frameworks. More flexible educational policies and curricula embracing holistic education and sustainable practices are needed.

Sufficient funding should be allocated across EU regions for (i) attracting teachers and enabling professional development, starting with initial teacher training, (ii) innovative teaching methods, (iii) modern infrastructure, including the adoption of laboratories and IT equipment that facilitate the use of AI, robotics, and other digital tools, ensuring equal opportunities in remote or rural areas.

Also, it is essential to raise awareness about the societal importance of STEM education. This includes advocating for public science events (e.g., researchers' night), launching media campaigns, and developing community-based STEM programmes. Informal learning also plays a crucial role; for instance, parents significantly influence children's aspirations and engagement, impacting their long-term academic outcomes. Exposure to non-formal education, e.g., in museums and science centres, also increases students' interest and participation in integrated STEM, STEAM or STE(A)M education.

Strengthening collaborations and cultivating synergies can help advance STEM policies. Schools, universities, businesses, government entities, civil society, local communities, libraries, museums, and science centres should all be engaged in this collective effort to foster community ownership. Educational institutions and industries must work together to align education with workforce needs, expose students to STEM careers, and develop mentorship and internship opportunities. Furthermore, developing support systems for educators, such as peer learning networks and coordination frameworks, can facilitate adopting and scaling integrated STEM, STEAM or STE(A)M approaches.

Principals can play a key role at the school level by exerting strong leadership and pursuing active learning approaches to STEM, such as whole school approaches, open schooling, and living labs.

Whole school approaches "imply collective and collaborative action in and by a school community to improve student learning, behaviour and well-being, and the conditions that support these"[27] by engaging the local community, school leaders, middle management, teaching and non-teaching staff, learners, parents, and families. Open schooling focuses on STEM-based collaborations within local communities on projects addressing societal challenges. A living lab is an open-innovation methodology where community actors participate horizontally to create STEM-based solutions to real problems.

In summary, integrated STEM, STEAM or STE(A)M education provide valuable perspectives to education, but there is no one-size-fits-all solution. Multifaceted, context-based actions must bridge existing skills gap and enhance engagement in STEM among European youth, while acknowledging the complexity of educational inequalities, including gender and diversity gaps.

Ultimately, adopting a comprehensive EU-wide STEM competence framework can enhance the implementation of STEM education in Member States. By ensuring policy coherence at the national, regional, and local government levels, initiatives can be scaled up further. This framework should also align with EU-level objectives, such as basic skills targets. It can serve as a tool to establish minimum criteria for classifying an educational activity as STEM and for students to possess specific levels of STEM competencies.

The framework should leverage insights from existing initiatives, involve stakeholders and experts through consultations, and align with active Erasmus+ and Horizon projects. Additionally, it should build on established frameworks like LifeComp,[28] DigComp,[29] and GreenComp.[30] Given the urgent need for teacher training in integrated STEM, STEAM and STE(A)M methods, a framework designed specifically for educators is essential, following the example of the Digital Competences Framework for Educators (DigCompEdu).[31]

## RESEARCH NEEDS

Given the lack of consensus on terminology and methodologies for integrated STEM and STEAM or STE(A)M education, a systematic literature review could help identify effective practices implemented by Member States. In particular, it is important to assess the efficacy of integrated STEM, STEAM or STE(A)M approaches and which integration strategies align best with current educational demands.

Establishing monitoring and evaluation systems or frameworks for STEM initiatives over time is essential. Using experimental and longitudinal designs is recommended to evaluate teaching and assessment practices and their impact on learning outcomes, and curriculum development. Additionally, future STEM research and EU programmes should clearly outline desired learning and teaching outcomes to effectively monitor student progress and teacher development, regularly disseminating findings with transparency.

**QUICK GUIDE**

**STEM education:** Combines science, technology, engineering, and mathematics in a multi- or interdisciplinary approach to create a unified, dynamic educational framework.

**Integrated STEM education:** STEM disciplines are seen as interconnected domains rather than isolated disciplines, mirroring the intricacy of real-world issues. Frequently relies on multi-, inter-, or transdisciplinary integration. Expands the skill set of core STEM education with transversal skills.

**STEAM or STE(A)M education:** Typically integrates core STEM disciplines with the broader perspectives of the arts, social sciences and humanities (SSH), along with other fields to tackle real-world challenges, mainly through multi-, inter-, and transdisciplinary approaches. It trains students with transversal skills relying on arts-based methods and approaches (design thinking, storytelling, visualisation) as well as complementing technical and transversal skills with social and ethical insights.

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