

Designing and Implementing the acaSTEMy Project – Trans-national Science, Technology, Engineering, and Mathematics Teacher Education Focusing on Transversal Competences and Sustainable Education

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ABSTRACT

This article addresses the internationally recognized need to strengthen the competences, professional capacity, and motivation of science, technology, engineering, and mathematics (STEM) educators working in schools, higher education institutions, and science-promotion organizations. The study draws on the experience of institutions from eight European countries and examines the challenges affecting STEM educator professional learning and collaboration across diverse educational contexts within the acaSTEMy project (hereafter referred to as acaSTEMy). The resulting framework provides a systematic basis for moving from the identification of challenges toward coordinated implementation across different institutional and national contexts. It also illustrates how evidence-informed strategic analysis can support the development of internationally collaborative approaches to STEM educator professional learning while accommodating contextual diversity. As such, this article seeks to contribute a conceptual and operational framework that can inform the design, implementation, and further research-based evaluation of sustainable STEM teacher education initiatives across Europe.

KEY WORDS: Sustainable education, strengths, weaknesses, opportunities, and threats dimension; teacher education; transversal competencies

INTRODUCTION

Within the context of Europe's twin green and digital transitions, teachers play a key role in preparing learners to respond to rapidly changing societal, technological, and environmental demands. Education, training, upskilling, and reskilling are increasingly recognized as essential for strengthening Europe's sustainable competitiveness, social fairness, and resilience (European Commission, 2020b). The Digital Education Action Plan 2021–2027 further emphasizes the need for high-quality, inclusive, and accessible digital education and for education and training systems capable of responding effectively to digital transformation (European Commission, 2020a). More recently, the European Science, Technology, Engineering, and Mathematics (STEM) education strategic plan has positioned STEM education as a strategic pillar of European education and skills policy, highlighting the need to develop a stronger and more inclusive STEM talent pipeline in response to technological change, labor-market demand, and Europe's future competitiveness (European Commission, 2025).

These developments are part of a broader shift in contemporary education policy from an emphasis on knowledge acquisition toward the development of competences, particularly so-called

transversal competences, also referred to as key competences, generic competences, or simply as 21st-century skills. Although terminology varies across policy and research contexts, these concepts broadly encompass the knowledge, skills, attitudes, and dispositions that learners need to participate effectively and responsibly in contemporary society.

Most transversal competence frameworks emphasize higher-order thinking, including critical and creative thinking, problem-solving, collaboration, communication, and decision-making. At the same time, competence development does not diminish the importance of disciplinary knowledge. Rather, deep disciplinary understanding and knowledge of interdisciplinary core ideas provide the conceptual foundation needed to interpret scientific phenomena, evaluate evidence, and apply knowledge in unfamiliar and real-world contexts (Duschl et al., 2021). Meaningful connections between prior knowledge, newly acquired knowledge, and its application can also strengthen learners' confidence and perceived self-efficacy. In parallel, digital competence and digital literacy have become integral components of contemporary competence development, reflecting the increasingly important role of digital technologies in education, professional life, and society (European Commission, 2020a).

Within this broader policy and educational context, acaSTEMy has sought to respond simultaneously to challenges associated with STEM teacher competence development, changing educational paradigms, sustainability, digitalization, professional mobility and collaboration, and the need to strengthen connections between science education and contemporary societal challenges. The project therefore approaches teacher professional learning not as the development of isolated skills, but as an interconnected process through which disciplinary, pedagogical, digital, social, sustainability-related, and future-oriented competences can be strengthened within STEM education.

A central concept within this approach is sustainable education, which, in acaSTEMy, encompasses two complementary dimensions. The first concerns education for sustainability, that is, developing learners' capacity to understand and engage with sustainable ways of living through societal issues that have a natural science and STEM dimension. This orientation is consistent with UNESCO's education for sustainable development: A roadmap (UNESCO, 2020), which positions education as an important contributor to the individual and societal transformation needed to address sustainability challenges and identifies educator capacity building as one of its priority areas. It is also aligned with the European GreenComp framework (Bianchi et al., 2022), which conceptualizes sustainability competence through four interconnected areas: Embodying sustainability values, embracing complexity in sustainability, envisioning sustainable futures, and acting for sustainability.

The second dimension concerns the sustainability of educational development itself. From this perspective, sustainability means ensuring that the knowledge, professional practices, networks, resources, and forms of collaboration generated through the project continue to contribute to teacher education and classroom practice beyond the formal funding period (European Commission, 2025). This includes enabling participating teachers and teacher educators to transfer, adapt, and further develop project approaches within their own professional contexts, maintaining access to project outputs, and strengthening institutional capacity for continued professional learning.

This emphasis on sustained professional learning is supported by recent research on STEM teacher professional development. Systematic reviews indicate that effective professional development extends beyond isolated training events and benefits from active participation, collaboration, meaningful engagement with teaching practice, and opportunities for continued professional learning (Huang et al., 2022; Rehman et al., 2025; Surahman and Wang, 2023). These findings support the acaSTEMy intention to connect professional development with mentoring, mobility, collaborative learning, digital education, and engagement with authentic STEM contexts rather than treating these as separate activities.

To support these aims, the acaSTEMy consortium has established a European partnership of STEM teacher education and professional development providers with broad geographical coverage, together with an extensive network of STEM teachers and other educational stakeholders. Particular attention has been given to involving and empowering partners from participating countries and wider to strengthening their participation in European-level teacher education collaboration. The partnership also builds on previous cooperation, expertise, and practices developed among European universities and other organizations through earlier European Commission-funded initiatives particularly SciCar and PROFILES (European Commission, n.d.-a, n.d.-b).

The acaSTEMy consortium brings together organizations from eight European countries and includes academic institutions, practice schools, policymakers, out-of-school learning organizations, STEM teacher associations, and representatives of the private sector. Its target groups consequently extend across different levels and settings of education and include university students and student teachers, practicing teachers, teacher educators, policymakers, and experts from science and science-related professional fields. Such collaboration is consistent with the increasing emphasis on connecting education and training institutions, research organizations, professional communities, and employment sectors in developing future STEM capacity (European Commission, 2025).

An important characteristic of acaSTEMy is the integration of initial teacher education and continuing professional development within the same collaborative structure. Universities and other teacher education providers work alongside STEM teacher associations, ministries and other public bodies responsible for school education, practice schools, out-of-school learning organizations, and employers in scientific and technological fields. This structure enables professional learning to be considered across the teacher career continuum rather than as a set of isolated pre-service and in-service interventions. It also reflects the OECD Teaching Compass (OECD, 2025), which positions teachers as lifelong professional learners, co-designers of learning, and agents of educational change whose professional agency and competences need to be supported through collaborative learning ecosystems.

Within this partnership, stakeholders have collaboratively designed and piloted approaches to professional mobility, mentoring, networking, and continuing professional learning. These activities aim to strengthen teachers' disciplinary, transversal, digital, sustainability-related, and future-oriented competences while promoting exchange between research, teacher education, schools, and other STEM learning environments. The broader intention is therefore not simply to provide individual professional development activities, but to create interconnected and sustainable approaches to STEM

teacher learning that can be adapted to different institutional and national contexts.

To operationalize these aims, acaSTEMy conceptualizes teacher competence development through four interconnected dimensions: Scientific, technological, societal, and transversal competence, embedded within the broader orientation of sustainable education. These dimensions are informed by the project's initial survey of teachers' self-perceptions concerning science-related issues and higher-order thinking skills, digital competences, social competences, and diversity. Together, these dimensions provide the conceptual basis for the subsequent design and development of acaSTEMy professional learning activities and for considering how teachers can be supported in enabling learners to use scientific and technological knowledge meaningfully, responsibly, and sustainably across different contexts.

METHODOLOGY

The study aimed to identify key strengths, weaknesses, opportunities, and threats (SWOT) influencing the development of STEM educator competences and, on this basis, to construct a framework for coordinated international action. The analysis was informed by an initial documentary review of relevant European and national policy documents, research literature, partners' practices, and contextual information from the participating countries. A SWOT framework was subsequently used as an analytical and strategic synthesis tool to structure the identified internal and external factors and to determine priority areas for development (Benzaghta et al., 2021). The analysis was conducted collaboratively by three experts, each representing a different focus area such as social science, management, or engineering. The assignment of findings related to the SWOT dimensions was validated by two experts.

Based on this analysis, a model was developed to operationalize the identified challenges by linking them with targeted actions in STEM teacher education and professional learning. The model integrated international collaboration, professional mobility, mentoring and networking, research-informed professional development, and the strengthening of transversal and digital competences. Particular attention was given to the diversity of learners, interdisciplinary approaches to STEM education, and the sustainability of educational change.

RESULTS

Table 1 highlights the main findings from the SWOT analysis and shows how the findings informed the acaSTEMy operational model.

Figure 1 illustrates how these identified needs, developmental activities, and supporting mechanisms are brought together within the acaSTEMy framework. It shows the pathway from the evidence-based identification of challenges to the development, piloting, and implementation of concrete professional-learning approaches and, ultimately, to sustainable and transferable outcomes for STEM teacher education. The framework therefore seeks to demonstrate how acaSTEMy needs to move from identifying European-level challenges and teacher-development needs toward providing practical solutions and outputs that can remain available and be adapted across different educational contexts in Europe and beyond.

DISCUSSION

The SWOT analysis highlights that the acaSTEMy consortium operates from a strong institutional and professional base, while at the same time revealing important structural and research-related challenges that need to be addressed if

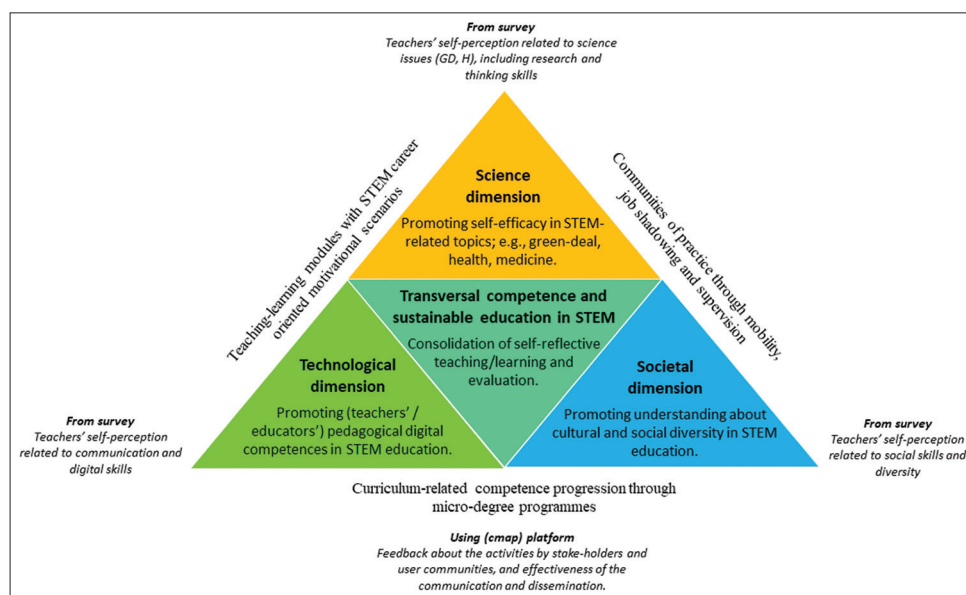


Figure 1: acaSTEMy framework linking identified teacher competence needs with the science, technological, societal, and transversal competence dimensions and the corresponding professional-learning activities and project outcomes

Table 1: SWOT analysis used for designing and implementing acaSTEMy in terms of research capacity, development opportunities, and sustainability challenges

SWOT dimension	Main findings	Implication for acaSTEMy
Strengths	Strong science education research expertise and extensive international research experience in most countries	Provides a strong basis for theoretically grounded teacher professional learning, research-informed development, and international collaboration.
Strengths	Doctoral and research programs across the partner institutions	Enables joint supervision, researcher development, capacity building, and research on teacher educator professional growth.
Strengths	Complementary expertise and diverse national and institutional contexts	Creates opportunities for comparative research and for examining how professional learning is influenced by cultural, institutional, and policy contexts.
Strengths	Availability of multiple sources of evidence	Supports methodological triangulation through questionnaires, interviews, observations, reflective accounts, teaching artefacts, concept maps, and institutional documentation.
Weaknesses	Absence of an initially unified research framework	As acaSTEMy was designed primarily as a Teacher Academy and capacity-building initiative, activities were not initially organized around common research questions, constructs, instruments, and longitudinal protocols.
Weaknesses	Variation in instruments and data-collection procedures	Limits comparability across countries and highlights the need for selected shared constructs and common research protocols.
Weaknesses	Limited baseline and longitudinal evidence	Restricts conclusions about changes over time and indicates the need for baseline, post-intervention, and delayed follow-up measures.
Weaknesses	Dependence on self-reported evidence	Perceptions and satisfaction provide valuable evidence but are insufficient by themselves to demonstrate changes in enacted professional practice.
Opportunities	Development of a shared European research agenda for STEM teacher professional learning	Enables coordinated research on teacher competences, agency, identity, interdisciplinarity, digital and sustainability competences, mentoring, mobility, and professional learning sustainability.
Opportunities	Researching professional mobility and job shadowing	Creates opportunities to investigate professional identity, agency, reflection, boundary crossing, learning from unfamiliar contexts, and transfer into practice.
Opportunities	Strengthening research-practice partnerships	Enables teachers, schools, associations, and universities to participate jointly in defining problems, generating evidence, and developing educational practices.
Opportunities	Developing pedagogically meaningful digital competence	Allows research to move beyond technology use towards examining how digital tools support inquiry, modeling, evidence evaluation, collaboration, argumentation, and assessment.
Opportunities	Conceptualizing sustainability and transformative competences	Provides a basis for strengthening systems thinking, futures thinking, sustainability values, and responsible action within STEM teacher education.
Opportunities	Promote micro-credentials as a research and professional-learning area	Opens research possibilities concerning accessibility, recognition, competence development, quality assurance, motivation, transfer to practice, and sustainability.
Opportunities	Enhance teacher identity and agency as outcomes of professional development	Extends evaluation beyond knowledge and skills to teachers' professional self-concept, agency, competence, and capacity to lead educational change.
Threats	Insufficient resources for online courses, micro-degrees, job shadowing, and joint supervision	May limit continuation and scaling of professional learning activities.
Threats	Partner expertise may not be accepted or implemented at institutional action level	May restrict transfer of project knowledge into institutional practice.
Threats	Low motivation among some participants in international training and job-shadowing activities	May reduce engagement and the professional impact of mobility activities.
Threats	Project duration may be too short to achieve paradigm shifts in science teacher education	Major changes in educational practice and institutional culture may require longer-term development.
Threats	Limited Master's-level research linked with sustainability education	May constrain the development of future research capacity in this area.
Threats	Poor societal attitudes towards STEM careers	May negatively influence recruitment, motivation, and long-term STEM participation.
Threats	Limited private-sector awareness of STEM teacher education challenges	May weaken collaboration between teacher education and STEM employment sectors.
Threats	Limited mutual understanding and motivation between associated partners and local lead organizations, including financial instability	May undermine sustained local collaboration and implementation.
Threats	Incomplete risk planning for maintaining project sustainability after funding ends	Creates uncertainty concerning continuation of activities, networks, and outputs beyond the project period.
Threats	External disruptions, such as pandemics, may postpone activities	May interfere with mobility, collaboration, implementation, and achievement of project goals.
Threats	Unexpected changes in human resources without adequate succession planning	May threaten continuity of expertise, management, and project-related activities.

STEM: Science, Technology, Engineering, and Mathematics, SWOT: Strengths, weaknesses, opportunities, and threats

sustainable change in STEM teacher education is to be achieved. The outcomes suggest that the value of acaSTEMy lies not only in providing professional development activities, mobility opportunities, mentoring, and networking but also in creating conditions for a more coherent and research-informed approach to STEM teacher professional learning across different European contexts.

The identified strengths are closely aligned with current international perspectives on the changing role of teachers. The OECD teaching compass (OECD, 2025) conceptualizes teachers not merely as implementers of curricula but as agents of curriculum change, emphasizing professional agency, competences, well-being, and participation in collaborative learning ecosystems. As such, the OECD learning compass emphasizes the development of knowledge, skills, attitudes, and values that enable learners and educators to act responsibly under conditions of complexity and uncertainty (OECD, 2019). From this perspective, the acaSTEMy emphasis on transversal competences, digital competence, professional collaboration, mobility, and continuous learning is consistent with broader international developments in teacher education.

At the same time, the SWOT analysis indicates that strong institutional expertise does not automatically translate into coherent professional learning structures. Although consortium partners have substantial experience in science education research, teacher education, international projects, and doctoral supervision, professional development opportunities remain unevenly distributed, international collaboration is often project-based, and mobility, mentoring, and micro-credential provision are not yet consistently embedded within teacher education systems. This tension between strong institutional capacity and fragmented implementation appears to be one of the central findings of the analysis.

This finding is consistent with recent research on teacher professional development. Effective professional learning is increasingly understood as an extended process rather than a sequence of isolated training activities. Sustained engagement, active participation, collaboration, coaching, reflection, and opportunities to apply new ideas in practice appear to be important conditions for meaningful professional learning (Ehlert and Souvignier, 2023; Rehman et al., 2025). The acaSTEMy activities therefore have greater potential when mobility, mentoring, modules, and collaborative learning are conceptualized as interconnected elements of teacher development rather than as separate project interventions.

A further implication concerns the nature of evidence used to assess professional development. The SWOT analysis suggests that evaluation of project activities cannot rely solely on participation rates, satisfaction surveys, or self-reported competence development. While such evidence is valuable for understanding participants' experiences, it provides limited information about how professional learning is enacted, transferred, and sustained. Recent reviews similarly identify extensive reliance on self-reported measures as a

methodological limitation in research on teacher competence, including digital competence (Smestad et al., 2023). For acaSTEMy, this points toward the need to combine self-report data with interviews, observations, reflective accounts, teaching artefacts, concept maps, lesson plans, or other forms of evidence that provide insight into changes in professional practice.

The international mobility and job-shadowing components of acaSTEMy are especially relevant in this respect. Their value cannot be interpreted simply through participants' positive perceptions of mobility. More significant research questions concern what teachers notice in unfamiliar educational contexts, how they interpret differences between educational systems, which practices they consider transferable, and how these experiences influence professional reflection, identity, and agency. Mobility can therefore be conceptualized as a form of professional boundary crossing, in which participants encounter different institutional, pedagogical, and cultural practices. Whether such experiences lead to sustained professional learning depends on opportunities for reflection, follow-up, adaptation, and integration into local practice.

The SWOT analysis also reinforces the importance of collaboration between universities, schools, teacher associations, and other professional organizations. The involvement of teachers and professional associations should extend beyond participation in dissemination activities. Research–practice partnership literature suggests that stronger relationships between research and practice emerge when practitioners contribute to identifying problems, interpreting evidence, and developing solutions rather than functioning merely as recipients of research outcomes (Sarmiento-Márquez et al., 2023; Sjölund, 2022). For acaSTEMy, such partnerships can strengthen both the relevance of professional development and the sustainability of project outcomes beyond the formal funding period.

Sustainability represents another important dimension emerging from the analysis. The European GreenComp framework (Bianchi et al., 2022; European Commission, 2025) defines sustainability competence through four interconnected areas: Embodying sustainability values, embracing complexity, envisioning sustainable futures, and acting for sustainability. These dimensions extend well beyond environmental knowledge and require teachers to support systems thinking, future-oriented reasoning, responsible decision-making, and action. The acaSTEMy modules, addressing sustainability and the Green Deal, can therefore be interpreted as part of a broader shift toward transformative science education in which teachers are expected to connect disciplinary knowledge with complex societal challenges.

A similar argument applies to digital competence. The SWOT findings suggest that teachers' access to digital resources and platforms alone is insufficient to promote students' digital competence. AcaSTEMy recognizes that digital competence needs to be interpreted pedagogically, focusing

on how technologies support inquiry, modeling, assessment, argumentation, communication, and interdisciplinary STEM learning. Thus, the central question is not whether teachers use digital tools, but how digital tools contribute to meaningful learning and to the development of competences required in contemporary STEM education.

Taken together, these findings suggest that acaSTEMy must not be conceptualized simply as a collection of professional development activities. A stronger interpretation is that the project provides an environment in which different forms of STEM teacher professional learning can be conceptualized, implemented, investigated, and compared. This creates a potential research agenda organized around four interconnected dimensions:

1. Developments require a stronger conceptual and theoretical foundation. Constructs such as transversal competence, professional agency, digital competence, sustainability competence, mentoring, interdisciplinary STEM competence, mobility, and professional learning need to be clearly defined and theoretically justified. Frameworks such as the OECD Teaching Compass, OECD Learning Compass, GreenComp, DigCompEdu (Redecker, 2017), and UNESCO Education for Sustainable Development provide useful foundations, but these need to be operationalized in relation to the specific purposes of STEM teacher education.
2. Greater attention needs to be given to implementation and professional learning processes. Research needs to investigate how teachers engage with professional development activities, which components they adopt or modify, which contextual factors enable or constrain implementation, and how mentoring or mobility experiences become translated into local practice. Such questions shift attention from whether an intervention is delivered towards understanding how and why it functions in particular contexts.
3. There is a need for stronger outcome and longitudinal evidence. The most important question is not only whether participants report positive experiences but also what changes, for whom, under which conditions, and whether these changes are sustainable. Relevant outcomes may include teacher knowledge, professional competence, identity, agency, interdisciplinary understanding, digital and sustainability competence, reflective practice, professional networks, and classroom practice. Where feasible, baseline and follow-up evidence need to be combined, and longitudinal approaches need to be incorporated into future research.
4. At the same time, causal interpretations need to remain cautious. acaSTEMy was designed primarily as a Teacher Academy and developmental initiative rather than as a controlled intervention study. Consequently, findings may support conclusions concerning professional development, perceived impact, association, implementation, contribution, or change, but do not necessarily demonstrate that acaSTEMy activities alone

caused observed outcomes. This distinction is particularly important when positioning project-derived studies for publication in research journals.

5. Fourth, the international structure of acaSTEMy creates significant potential for comparative and system-level research. Differences between participating countries in teacher professional development, mentoring, mobility, micro-credentials, digital education, sustainability education, teacher associations, and institutional support, provide opportunities to identify both common patterns and context-dependent differences. The intended purpose of such comparisons is not to rank national systems, but to examine which principles may be transferable and which depend on particular institutional, cultural, or policy contexts.

Overall, the SWOT analysis suggests that the major contribution of acaSTEMy lies in connecting three interrelated levels of development. At the teacher level, the focus is on professional knowledge, competences, identity, agency, reflection, and practice. At the program level, attention is directed toward the design and implementation of modules, mentoring, mobility, job shadowing, digital learning, and micro-credentials. While, at the system level, the emphasis shifts toward institutional collaboration, professional networks, teacher associations, policy development, and sustainability.

Seen in this way, acaSTEMy provides more than a platform for delivering teacher education activities. It offers a basis for investigating how innovative forms of STEM teacher professional learning are conceptualized, implemented, experienced, transferred, and sustained across diverse European contexts. The findings also reinforce the need to move from fragmented project-based activities toward more coherent, research-informed, and institutionally embedded approaches to STEM teacher professional development.

CONCLUSION

The updated SWOT analysis indicates that strengthening STEM teacher education requires attention not only to individual professional development activities but also to the wider conditions in which teacher learning, program development, institutional collaboration, and policy interact. The resulting framework therefore positions acaSTEMy across three interrelated levels:

- The teacher level, focusing on professional knowledge, competences, agency, identity, beliefs, reflection, and practice;
- The program level, addressing the design, implementation, and outcomes of modules, mobility, job shadowing, mentoring, digital learning, and micro-credentials; and
- The system level, encompassing teacher education structures, institutional collaboration, research–practice partnerships, professional associations, policy, and sustainability.

This multi-level perspective reflects current developments in international teacher education research and policy, particularly

the shift from viewing teachers primarily as recipients of professional development toward recognizing them as active professional learners, co-designers, knowledge producers, and agents of educational change (OECD, 2025). From this perspective, sustainable improvement in STEM teacher education depends on creating coherent links between teachers' professional learning, the design of development programs, and the institutional and policy environments that enable or constrain change.

The analysis further suggests that future STEM teacher education initiatives needs to move beyond fragmented and short-term project activities toward more sustained, research-informed, and collaboratively designed professional learning structures. Involving international mobility, mentoring, digital learning, interdisciplinary STEM education, and micro-credentials have greatest potential when they are embedded within coherent professional learning pathways and supported by institutional networks, research-practice partnerships, and opportunities for continued reflection and collaboration.

From the research perspective, the main implication is the need to examine not only whether professional development activities are implemented successfully, but also

- How they are experienced?
- What changes they support?
- Under which conditions such changes occur? and
- Whether these changes are sustained over time?

This requires theoretically grounded constructs, multiple sources of evidence, longitudinal follow-up where feasible, and sensitivity to national and institutional context.

acaSTEMy therefore provides a useful conceptual and operational basis for developing a European research agenda on STEM teacher professional learning. Its contribution lies not in proposing a single transferable model for all contexts, but in identifying interconnected principles through which teacher-level development, program-level innovation, and system-level support can be aligned. Such alignment is essential if STEM teacher education is to respond effectively to rapidly changing scientific, technological, societal, and sustainability-related challenges while maintaining the capacity for continued professional and institutional learning.

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