Co-funded by the European Union

TRANSNATIONAL REPORT WITH RECOMMENDATIONS

ANALYSIS OF THE STATE OF ART IN STEM HIGHER EDUCATION

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2

Project Reference: 2024-1-BG01-KA220-HED-000253761

Table of Contents

INTRODUCTION

In the 21st century, higher education institutions face the dual challenge of keeping pace with rapid technological advancements and addressing global societal needs. The demand for graduates who are not only highly skilled in science, technology, engineering, and mathematics (STEM) but also capable of thinking critically, solving complex problems, and working collaboratively across disciplines has never been greater. As economies become more knowledge-driven and innovation-centered, the role of higher education in preparing learners for an uncertain and fast-evolving future has come into sharper focus.

In this evolving educational landscape, STEM education is recognized as a cornerstone of national competitiveness, economic resilience, and sustainable development. However, the traditional compartmentalized teaching methods and discipline-bound approaches often fail to reflect the interconnected realities of the modern world. To address this, higher education systems are increasingly moving toward integrated, interdisciplinary, and learner-centered models of instruction-models that emphasize problem-based learning, research engagement, and digital innovation.

The Erasmus+ project "Master Degree in Integrating Innovative STEM Strategies in Higher Education" responds to this urgent need by designing and piloting a cross-national Master's program that incorporates innovative pedagogies, cutting-edge technologies, and strategic partnerships between universities, schools, and industry. The project brings together institutions from Bulgaria, Serbia, Türkiye, and Uzbekistan, each with unique educational contexts, challenges, and opportunities, to co-create a shared framework for future-ready STEM education.

The overarching objective of the project is to build capacity for higher education institutions to deliver high-quality, inclusive, and innovation-oriented STEM programs. This involves rethinking how STEM is taught and learned in universities, how future teachers are trained, and how institutional ecosystems support the development of sustainable and scalable educational models. The project also emphasizes the integration of key competencies for sustainable development and digital transformation, thus aligning with the European Union's strategic vision for a green and digital future.

This Transnational Report with Recommendations is a key output of the project. It is based on a comprehensive analysis of national reports submitted by the partner countries and aims to synthesize the findings into a consolidated understanding of the current state of STEM education

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

in higher education institutions across the participating countries. It highlights shared challenges, identifies good practices, and proposes actionable recommendations that will guide the development and implementation of the joint Master's degree.

The report begins with an overview of the current state of STEM education in each partner country, drawing attention to both systemic strengths and persistent gaps. It then offers a transnational analysis that explores the common challenges faced across the region-such as insufficient integration of interdisciplinary approaches, outdated curricula, lack of practical training opportunities, and a shortage of skilled STEM educators. These challenges are compounded by disparities in digital infrastructure, low student motivation in some disciplines, and limited engagement with the labor market.

Despite these challenges, the report also uncovers numerous examples of innovation and progress. From Bulgaria's national program for building school STEM centers and integrating virtual reality into teacher training, to Türkiye's STEM hubs linked to industry and research, to Serbia's participatory and project-based teaching models, and Uzbekistan's rapid modernization of STEM curricula-there is much to be learned from the diverse strategies employed across the partner countries.

The strategic section of the report proposes a shared model for implementing an interdisciplinary STEM Master's degree. This model is grounded in active learning, research-based pedagogy, and collaborative curriculum development. It emphasizes sustainability, digital innovation, and inclusivity as cross-cutting themes and advocates for stronger links between universities, schools, and the labor market. The proposed model aims not only to improve academic performance but also to foster civic engagement, entrepreneurship, and lifelong learning skills.

Finally, the report offers a set of recommendations at the policy, institutional, and programmatic levels. These recommendations are intended to inform decision-makers, university leaders, curriculum developers, and educators who are working to enhance the quality and relevance of STEM education in higher education.

In preparing this report, the project partners have embraced a participatory and evidence-based approach. Each national report was developed using both qualitative and quantitative methods, including literature reviews, policy analyses, surveys, and expert interviews. This ensures that the findings are not only grounded in national realities but also reflective of broader European and global trends in STEM education.

In conclusion, this transnational report serves as both a reflective and forward-looking document. It underscores the urgency of transforming STEM education to meet contemporary needs and illustrates how regional cooperation can lead to systemic innovation. As the project moves forward into the implementation and piloting phases of the joint Master's program, the insights and recommendations presented here will serve as a strategic compass, ensuring that the outcomes are impactful, sustainable, and transferable across educational systems.

CURRENT STATE OF STEM EDUCATION IN PARTNER COUNTRIES

The state of STEM education in higher education varies across countries due to differences in national priorities, policy environments, institutional capacity, and socio-economic conditions. In the context of the Erasmus+ project "Master Degree in Integrating Innovative STEM Strategies in Higher Education," the partner countries - Bulgaria, Serbia, Türkiye, and Uzbekistan-represent diverse stages of integration of STEM approaches in higher education. This section presents a comprehensive overview of each country's landscape, highlighting both structural strengths and systemic gaps.

1. Bulgaria

In recent years, Bulgaria has taken significant steps toward aligning its education system with global trends in STEM. At the policy level, strategic documents such as the National Strategy for the Development of Higher Education (2021–2030) and the National Development Programme Bulgaria 2030 emphasize the role of STEM as a driver of innovation and economic growth. These frameworks prioritize investments in digital education, research infrastructure, and green transition-central components of STEM capacity building.

The Ministry of Education and Science has spearheaded several national programs, most notably the *"Building a School STEM Environment"* initiative, which has led to the development of over 2000 STEM centers in schools across the country. Furthermore, the establishment of a National STEM Center in Sofia Tech Park aims to serve as a hub for teacher training, interdisciplinary research, and innovation. This national momentum has filtered upward into higher education, with several universities-such as South-West University "Neofit Rilski," Plovdiv University, and Sofia University-introducing STEM-focused courses and research projects.

However, challenges remain. Higher education curricula in many STEM disciplines are still heavily theoretical, and project-based, interdisciplinary, or digital teaching methods are underutilized. There is an ongoing need for professional development programs for university educators, particularly in areas such as artificial intelligence, sustainability, and edtech integration. Moreover, the collaboration between universities and the labor market, while improving, is not yet robust enough to provide students with consistent opportunities for internships, research apprenticeships, or entrepreneurial training.

A 2024 survey of Bulgarian educators highlighted the strong interest in upgrading STEM-related competencies, with more than 80% of respondents expressing interest in enrolling in an advanced STEM degree program. This is a promising indicator for the future Master's program envisioned by this project.

2. Serbia

Serbia has made steady progress in modernizing its educational framework, and STEM education is increasingly recognized as a national priority. In higher education, several universities-including the University of Niš and the University of Novi Sad-have introduced new STEM-related courses and modules in recent years, particularly in engineering, informatics, and natural sciences. Many of these initiatives are supported by European projects, donor agencies, and bilateral cooperation agreements.

A symbol of Serbia's approach to STEM is its emphasis on methodological development. University pedagogy in Serbia is gradually shifting from lecture-based delivery to more interactive and exploratory learning models. Innovative teaching strategies, such as flipped classrooms, peer-led inquiry, and project-based assessment, are gaining traction, especially in STEM faculties. Teacher training colleges are also revising their curricula to include courses on digital pedagogy and STEM integration.

Despite this progress, Serbia faces structural and financial limitations. Investment in university-level research infrastructure, particularly in regional institutions, remains uneven. Some STEM faculties operate with outdated laboratory equipment and lack access to advanced digital tools. Moreover, interdisciplinary integration is not yet systemic-while isolated programs promote collaboration between departments (e.g., engineering and environmental sciences), most academic structures still operate within traditional disciplinary frameworks.

One of the strengths of the Serbian system is its popular engagement. Numerous student-led STEM clubs, competitions, and innovation hubs have emerged in the past five years. The annual "Days of Science" festival and various hackathons promote STEM literacy and community involvement. These platforms offer fertile ground for embedding project-based learning into the new Master's degree structure.

The need for capacity building in terms of academic staff development, institutional support for innovation, and internationalization remains critical. Serbia’s inclusion in this Erasmus+ consortium is therefore a timely opportunity to advance reform in STEM education through peer learning and strategic cooperation.

3. Türkiye

Türkiye has a well-developed higher education system, with more than 200 universities and a significant number of graduates in science and engineering. In recent years, STEM education has become a policy focus at both national and institutional levels. The Turkish Higher Education Council (YÖK) has initiated reforms aimed at enhancing the quality and relevance of university programs, particularly those related to science and technology.

STEM is increasingly integrated into Türkiye’s educational research agenda, supported by institutions such as TÜBİTAK (Scientific and Technological Research Council of Türkiye) and the Ministry of National Education. University faculties in education, engineering, and science have begun incorporating STEM methodologies into their teacher training programs. For instance, Middle East Technical University (METU) and Bahçeşehir University are leading research and training centers in STEM education, offering both theoretical and applied programs.

A distinguishing feature of Türkiye’s STEM landscape is the role of STEM centers-dedicated spaces for teacher training, student workshops, and industry collaboration. These centers offer hands-on experiences in robotics, electronics, and environmental engineering. They are often supported by regional development agencies and private-sector partners, creating a strong link between academia and real-world applications.

However, challenges persist. While interest in STEM is high, implementation is uneven. Many universities do not yet offer formal interdisciplinary STEM courses, and integration across faculties is limited. Additionally, rural and underfunded institutions struggle with resource constraints and limited access to advanced technologies. There is also a need to ensure gender equity in STEM fields, where female participation in some engineering and tech-related disciplines remains disproportionately low.

Türkiye has also made notable progress in green education and sustainability integration. Several universities have launched courses and research programs related to climate change, renewable energy, and environmental policy, aligning well with the project's focus on innovative and future-oriented STEM.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

The Turkish national report points to a robust foundation of expertise, infrastructure, and policy support that can be leveraged to co-design a high-quality joint Master's program.

4. Uzbekistan

Uzbekistan represents a dynamic and emerging context for STEM education in higher education. Since 2017, the government has launched wide-ranging reforms aimed at modernizing the education sector, internationalizing universities, and expanding the role of research and innovation in national development. The Ministry of Higher Education, Science and Innovation has introduced policies to align university curricula with European and international standards, with particular attention to science and technology fields.

STEM education in Uzbekistan is framed as a strategic national priority. In the past five years, there has been significant investment in upgrading infrastructure, launching centers of excellence, and introducing new educational technologies. Universities such as Tashkent State Pedagogical University and the National University of Uzbekistan have been tasked with leading curriculum reform and teacher education in STEM fields.

Despite these positive developments, STEM education in Uzbekistan remains in a transitional phase. Many institutions still rely on traditional didactic methods, and capacity for research-based and interdisciplinary instruction is limited. There is a lack of experienced faculty in modern STEM pedagogy, as well as limited access to international peer networks and research collaboration opportunities.

Nevertheless, Uzbekistan's educational strategy emphasizes rapid digitalization, integration of English-language instruction, and engagement with global partners. This creates fertile ground for introducing an innovative joint Master's program. Pilot projects on coding, robotics, and environmental science have already been launched in several teacher training institutions, with strong student interest and institutional support.

One promising aspect of Uzbekistan's context is the political will to reform. The national strategy for the development of higher education to 2030 includes explicit goals related to STEM: increasing enrollment in science and engineering disciplines, training teachers in digital education, and expanding partnerships with international universities.

Participation in the Erasmus+ project marks a key step in Uzbekistan's trajectory toward becoming an active member of the European Higher Education Area. The country's involvement ensures both a valuable regional perspective and a strong commitment to capacity building.

Summary of National Contexts

While each partner country presents a distinct profile, common themes emerge:

- **Policy Support**: All countries recognize the strategic importance of STEM and have integrated STEM-related goals into national education strategies.
- **Curriculum Modernization**: Efforts are underway to reform curricula toward interdisciplinary, project-based, and sustainability-oriented models.
- **Challenges**: These include limited resources, insufficient faculty training, and weak institutional collaboration across sectors.
- **Opportunities**: There is strong interest among educators and students in participating in advanced STEM training programs. Existing initiatives, such as national STEM centers, international research projects, and innovation hubs, offer scalable models.

These shared realities provide a compelling foundation for the joint development of a transnational Master's program that will both address current gaps and harness existing strengths.

TRANSNATIONAL ANALYSIS – COMMON CHALLENGES

The national reports from Bulgaria, Serbia, Türkiye, and Uzbekistan present rich and contextually grounded insights into the current state of STEM education in higher education institutions. Despite regional and systemic differences, a detailed comparative analysis reveals a series of shared challenges that hinder the full implementation of integrated, innovative, and future-oriented STEM strategies. These challenges are grouped below into six key thematic areas: policy and governance, curriculum and pedagogy, faculty capacity, infrastructure and resources, research integration, and inclusivity and access.

1. Fragmented Policy Implementation and Governance Gaps

While all partner countries have adopted national strategies that support STEM education and innovation, the actual implementation at the institutional level remains fragmented. In some contexts, STEM policies are broad and aspirational but lack mechanisms for operationalization in universities and faculties. For example, while Bulgaria and Türkiye have established national STEM centers and policies promoting digital transformation, the integration of these efforts across faculties - especially those preparing teachers-is not always systematic.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

Universities often function in isolated policy domains, disconnected from national innovation agendas or educational reform strategies. This results in duplication of efforts, inefficient resource use, and missed opportunities for synergy between education and research. Moreover, governance models at universities can be rigid, with decision-making concentrated at central administrative levels, limiting the autonomy of faculties or departments to innovate their curricula or teaching practices.

There is a critical need for better vertical alignment between national STEM goals and institutional practices, supported by performance-based funding, professional incentives for faculty innovation, and stronger accountability mechanisms.

2. Curriculum Rigidity and Limited Interdisciplinary Integration

A central challenge across all four countries is the limited integration of interdisciplinary learning into higher education curricula. Most university programs in STEM disciplines remain discipline-bound, with little flexibility for cross-departmental collaboration or modular course design. Interdisciplinary topics such as sustainability, artificial intelligence, robotics, and climate change are often introduced as elective or peripheral subjects rather than core components of teacher training and pedagogical programs.

Moreover, the current curriculum design in many institutions prioritizes theoretical knowledge over practical application, which inhibits students' ability to transfer skills across domains or solve real-world problems using an integrated approach. This is especially problematic in teacher education programs, where future educators must be equipped to facilitate STEM learning in dynamic, project-based environments.

A related issue is the absence of alignment between school-level STEM reforms and university-level teacher preparation. While primary and secondary education systems are introducing integrated STEM programs (e.g., through STEM centers in schools), higher education institutions often lag behind, continuing to train teachers in traditional, single-subject methodologies. This disconnect creates a critical gap in the pipeline of STEM-competent educators.

3. Faculty Readiness and Pedagogical Training Deficits

Across all partner countries, the successful implementation of innovative STEM strategies is hindered by a shortage of trained faculty who possess both disciplinary expertise and modern pedagogical competencies. While many STEM instructors are well-qualified in their scientific fields, they frequently lack training in active learning methodologies, digital pedagogy, and interdisciplinary curriculum design.

The transition from traditional, lecture-based instruction to more student-centered and problem-based approaches has not been fully institutionalized. Even where faculty express interest in updating their teaching strategies, they are often constrained by limited access to professional development, rigid workloads, and lack of institutional support.

Furthermore, there is a notable absence of structured mentoring or communities of practice that facilitate peer learning and the exchange of innovative teaching practices across institutions. University teaching excellence centers, where they exist, tend to focus on general pedagogy and rarely offer specialized support for STEM faculty.

The need to build faculty capacity at scale-particularly in the context of the digital and green transitions - is a priority for all countries and must be a core focus of the proposed Master's program.

4. Infrastructure Inequalities and Limited Digital Resources

Despite growing investment in education infrastructure in countries like Bulgaria and Türkiye, significant disparities remain in access to quality laboratories, digital tools, and virtual learning environments, particularly in regional or under-resourced universities. These disparities limit the ability of institutions to offer hands-on, experiential STEM learning at scale.

In Uzbekistan, while new educational centers are being constructed, many existing institutions still operate with outdated equipment, poor internet connectivity, and insufficient access to e-learning platforms. Similarly, in Serbia, although innovation hubs exist in certain universities, they are often the result of international projects and are not yet mainstreamed across the higher education system.

Even in better-equipped institutions, resource utilization is suboptimal, and faculty and students may lack training in how to integrate these technologies into teaching and learning. Access to simulation tools, 3D modeling software, robotics kits, and virtual laboratories is uneven, and many institutions are not prepared to support hybrid or blended learning formats on a sustainable basis.

Addressing these infrastructure gaps requires not only investments in equipment and connectivity but also systemic planning, capacity building, and the development of institutional strategies for technology-enhanced STEM education.

5. Weak Research-Teaching Linkages in STEM Fields

While all partner countries are engaged in STEM research activities to varying degrees, there is often a disconnect between research and teaching in universities. Academic research is frequently disconnected from curriculum development, and opportunities for students to participate in research projects or innovation challenges remain limited.

This disconnect is especially problematic in the context of teacher education, where engagement with research is essential to cultivating reflective, inquiry-driven practitioners. Without structured opportunities for students to engage with emerging scientific and technological developments, higher education programs risk preparing graduates who are out of step with contemporary STEM practices.

The lack of funding and incentives for pedagogical research in STEM, particularly interdisciplinary research, further compounds the issue. In many institutions, publication and research assessment frameworks prioritize traditional outputs over educational innovation, discouraging faculty from investing time in curriculum reform or STEM teaching research.

Creating stronger research-teaching linkages - including through student-led projects, applied research modules, and innovation labs-is essential to building a vibrant STEM learning ecosystem.

6. Inequities in Access and Participation

Another cross-cutting challenge is the persistent inequality in access to STEM education, especially among underrepresented groups. Gender disparities remain evident in many engineering and technology-related fields, and students from rural, minority, or low-income backgrounds are significantly less likely to enroll in advanced STEM programs or benefit from extracurricular STEM initiatives.

In some partner countries, such as Türkiye and Bulgaria, efforts have been made to promote gender inclusion and regional equity, but these are often project-based and temporary, rather than embedded in systemic reforms. The lack of culturally responsive teaching materials, inclusive pedagogies, and targeted outreach campaigns further hinders the diversification of STEM fields.

Moreover, persons with disabilities remain largely excluded from STEM programs due to inadequate support structures, inaccessible infrastructure, and lack of assistive technologies. These inequities are not only a matter of social justice but also a lost opportunity to expand the talent pool for national and regional development.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

Ensuring inclusive and equitable STEM education must be a foundational principle of the Master's program, including through inclusive curriculum design, universal design for learning, and targeted recruitment and retention strategies.

The transnational analysis of the national STEM reports confirms that while significant progress has been made in promoting STEM education across the partner countries, major systemic challenges remain. These challenges are not isolated to one context but are shared across the region, signaling the need for coordinated, cross-country solutions.

The upcoming Master's degree in Integrating Innovative STEM Strategies must be carefully designed to address these challenges head-on-by fostering curriculum flexibility, building faculty capacity, promoting equity, strengthening research-teaching linkages, and leveraging digital innovation to democratize access to high-quality STEM learning.

TRANSNATIONAL ANALYSIS – GOOD PRACTICES AND INNOVATIONS

Despite the structural and pedagogical challenges outlined in the previous section, the national reports also reveal a wealth of innovative practices and forward-looking initiatives that offer valuable insights for transforming STEM education in higher education. These practices span curriculum design, digital integration, institutional cooperation, teacher training, and engagement with sustainability and inclusion goals. By examining and comparing these good practices, the partner countries can draw upon one another's strengths to build a resilient and innovative joint Master's degree model.

1. National STEM Centers and Local Innovation Hubs (Bulgaria, Türkiye)

A standout initiative in Bulgaria is the "Building a School STEM Environment" program, funded through the National Recovery and Resilience Plan. The program includes the development of over 2,200 STEM centers across public schools, with each designed to offer students access to modern laboratories, collaborative learning spaces, and interdisciplinary project environments. Although initially school-based, this initiative has had a spillover effect on higher education, particularly in teacher training faculties tasked with preparing future educators for STEM-rich environments.

Complementing this is the planned National STEM Center at Sofia Tech Park, which aims to serve as a hub for teacher professional development, applied STEM research, and pedagogical innovation. This center reflects a strategic approach to aligning national infrastructure with digital, green, and pedagogical priorities, and could serve as a model for regional hubs in other countries.

In Türkiye, university-affiliated STEM centers-such as those at Bahçeşehir University and METU-offer workshops, robotics labs, and school-university collaborative activities. These centers not only enhance teacher and student engagement but also act as nodes in wider industry-academia partnerships, supporting applied research and entrepreneurship among STEM students.

The successful integration of physical infrastructure, policy vision, and teacher training in both countries demonstrates the value of STEM centers as anchor points for implementing broader systemic change.

2. Interdisciplinary and Sustainability-Oriented Curriculum Innovations

Several institutions across the partner countries are actively integrating sustainability and environmental education into their STEM programs-an approach aligned with the "Green STEM" concept promoted in European education policy.

In Bulgaria, the South-West University "Neofit Rilski" and Plovdiv University have developed elective modules on renewable energy, green chemistry, and sustainable development within STEM-related teacher training programs. These modules combine scientific theory with hands-on learning and real-world problem-solving, such as projects involving solar energy kits or climate data analysis. Additionally, 3D modeling tools and VR simulations have been introduced to support project-based learning on environmental issues.

Türkiye has demonstrated leadership in this domain through TÜBİTAK-funded research and educational projects that promote environmental awareness in STEM fields. For instance, several universities run student-led green engineering labs where learners prototype eco-friendly devices and conduct impact assessments.

These efforts reflect a broader regional shift toward aligning STEM education with the Sustainable Development Goals (SDGs) and equipping graduates with the knowledge and ethics to contribute to global climate resilience and ecological innovation.

3. Emerging Digital Pedagogies and EdTech Integration

Digital transformation is reshaping education globally, and each partner country has made notable progress in integrating educational technology (edtech) into STEM teaching and learning.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

In Bulgaria, various national and institutional projects have introduced VR and AR technologies in science education, particularly in chemistry, biology, and engineering. For example, through the VRinHE project, students use immersive simulations to visualize molecular structures, explore renewable energy systems, or model physical phenomena. Teachers are trained to use these tools effectively, ensuring that technology enhances-not replaces-meaningful pedagogy.

Serbia is leveraging platforms like Moodle, Microsoft Teams, and interactive whiteboards to support blended learning and flipped classroom models in STEM faculties. Additionally, universities have begun incorporating micro-credentialing systems that allow students to gain digital badges for specific technical skills such as coding, data analysis, or digital fabrication.

Türkiye's innovation lies in integrating robotics and artificial intelligence into teacher education. Pre-service teachers receive training on coding platforms such as Scratch, Arduino, and Python to help them design interactive STEM lessons. STEM centers often feature smart classrooms equipped with programmable sensors, encouraging the practical application of digital tools in classroom scenarios.

These examples underscore the importance of digital literacy and pedagogical adaptation, which must be core components of the joint Master's program.

4. University-School Partnerships and Practicum-Based Learning

A critical feature of effective STEM programs is the establishment of robust partnerships between higher education institutions and schools. These partnerships not only facilitate real-world teacher training experiences but also encourage innovation diffusion from universities into school systems.

In Serbia, the University of Niš has piloted school-university learning labs, where student teachers co-teach STEM modules under the guidance of mentors. These modules emphasize inquiry-based learning, data collection, and hands-on experimentation. The model has proven successful in improving student outcomes and boosting teacher confidence.

Uzbekistan has adopted a pilot mentoring scheme for teacher trainees, pairing them with experienced STEM educators in leading secondary schools. These programs provide early exposure to classroom environments, build reflective practice, and promote collaborative lesson planning.

In Bulgaria, under the empowerSTEAM initiative, STEAM camps and escape room formats are used to bring together pre-service teachers and students in immersive problem-solving contexts.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

These experiences are structured as “learning labs” where theory meets practice in a controlled but realistic setting.

Such partnerships highlight the value of practice-oriented teacher training and the need to embed fieldwork and co-teaching models into the new Master’s curriculum.

5. Research-Based Teaching and Student Innovation Projects

The integration of research into teaching is a hallmark of quality higher education. Across the consortium, there is growing recognition of the need to engage students in applied, interdisciplinary research within STEM fields.

In Türkiye, many faculties require students to complete capstone STEM projects, which involve designing a prototype, conducting user research, or solving an authentic community problem. These projects are often showcased in national STEM fairs or linked to industrial partners.

In Bulgaria, students in teacher education programs are increasingly involved in action research, investigating the impact of STEM teaching strategies in real classroom settings. This not only improves instructional practice but also fosters a mindset of continuous professional inquiry.

Uzbekistan is in the early stages of launching undergraduate research fellowships, encouraging STEM students to participate in faculty-led projects related to green technologies, smart agriculture, and energy innovation.

These examples point to the need for research-integrated teaching frameworks, where inquiry, experimentation, and reflection become standard practices in the learning journey.

6. Inclusive STEM Practices and Gender Equity Models

Equity and inclusion are emerging priorities in STEM education policy and practice. Several initiatives in the partner countries are working to bridge participation gaps, especially for women, rural learners, and marginalized communities.

In Türkiye, STEM centers run “Girls in STEM” mentorship programs, pairing secondary school students with female university students and professionals in STEM careers. These programs include coding bootcamps, maker workshops, and career panels, aiming to challenge stereotypes and build confidence.

Bulgaria’s STEM Jam Festival and the empowerSTEAM city model encourage community-level participation through accessible events and cross-sector partnerships. Activities such as citizen science projects, design challenges, and inclusive coding workshops draw in diverse learners and promote positive role models.

Serbia and Uzbekistan are piloting universal design approaches in STEM classrooms, adapting content and delivery to support learners with disabilities or special educational needs.

These inclusive models underscore the necessity of ensuring that the new Master's program intentionally integrates diversity, equity, and inclusion (DEI) principles, from recruitment strategies to course content and delivery methods.

The partner countries in this Erasmus+ project offer a diverse and rich ecosystem of good practices in STEM higher education. These innovations, while context-specific, provide scalable and transferable strategies that can inform the co-design of the joint Master's degree.

Key success factors include:

- The establishment of STEM centers as physical and pedagogical hubs.
- Integration of sustainability and digital transformation into curricula.
- Active collaboration between universities and schools.
- Emphasis on experiential learning and student research.
- Inclusive and gender-sensitive teaching approaches.

Building on these examples, the upcoming Master's program should serve not only as an academic qualification but also as a laboratory for innovation, helping reshape how STEM is taught, learned, and experienced across the partner institutions.

STRATEGIC PLAN FOR IMPLEMENTING A MODEL FOR TRAINING

The analysis of national contexts, challenges, and innovative practices across Bulgaria, Serbia, Türkiye, and Uzbekistan provides a strong foundation for designing and implementing a joint Master's degree program that reflects the core objectives of the Erasmus+ project "Master Degree in Integrating Innovative STEM Strategies in Higher Education."

This section outlines the strategic framework for implementing an interdisciplinary, inclusive, and innovation-driven Master's program. The strategy rests on five interrelated components:

1. **Curriculum Design**

2. **Pedagogical Model**
3. **Digital and Physical Infrastructure**
4. **Institutional and International Collaboration**
5. **Monitoring, Evaluation, and Sustainability**

Each of the above elements is supported by operational goals and guiding principles intended to ensure the program is responsive to partner country contexts while aligned with European quality assurance and lifelong learning standards.

1. Curriculum Design: Modular, Interdisciplinary, and Competency-Based

A key strategic objective is to develop a modular and flexible curriculum that reflects the complexity of modern STEM education while allowing for localization and contextual adaptation.

The curriculum will include the following core thematic clusters:

- **Innovative STEM Pedagogies**: Courses will cover project-based learning, inquiry-based science education, flipped classroom models, and design thinking.
- **Digital Transformation in Education**: Modules on edtech integration, coding, simulation tools (e.g., VR/AR), AI in classrooms, and data literacy.
- **Green STEM and Sustainability**: Topics such as climate change education, renewable energy systems, environmental science, and eco-design principles.
- **Entrepreneurship and STEM Policy**: Focused on education innovation ecosystems, startup thinking, and education-business collaboration.
- **Research in STEM Education**: Methodological training in action research, mixed methods, educational design research, and ethics.

The curriculum will be aligned with the European Qualifications Framework (EQF) at Level 7, ensuring comparability across partner countries. A credit-based structure will follow the European Credit Transfer and Accumulation System (ECTS), enabling recognition of learning outcomes within and beyond the consortium.

Moreover, a blended learning format will be adopted-offering flexibility through online coursework combined with intensive onsite learning labs, fieldwork, and internships. This approach accommodates working professionals and supports transnational mobility within the program.

2. Pedagogical Model: Learner-Centered and Practice-Based

The Master's program will be guided by a learner-centered philosophy, shifting the focus from knowledge transmission to knowledge construction and application. Learning environments will foster critical thinking, creativity, problem-solving, and collaborative learning.

Key pedagogical features include:

- **Project-Based Learning (PBL)**: Students will engage in interdisciplinary projects addressing real-world STEM challenges (e.g., designing a STEM curriculum for underserved schools or prototyping green tech tools for the classroom).
- **Co-Teaching and Mentorship**: Faculty across disciplines and partner universities will collaborate in course delivery. Students will be assigned mentors to guide them through research and practice components.
- **STEM Learning Labs**: Practical workshops and simulation sessions in STEM centers will provide immersive learning experiences using robotics kits, 3D printers, and digital microscopes.
- **Reflective Practice**: Learning journals, case study analysis, and micro-teaching sessions will be embedded to cultivate self-awareness and professional growth.

The program will also promote transversal competencies such as digital citizenship, intercultural communication, and ethical leadership-equipping graduates to become agents of change in diverse educational settings.

3. Digital and Physical Infrastructure: Building Enabling Environments

A successful implementation of this program depends on robust infrastructure that supports technology-enhanced, collaborative, and accessible learning.

Each partner institution will identify and/or enhance a dedicated STEM Learning Hub, equipped with:

- Smart boards and AR/VR labs
- 3D printing and modeling workstations

- Robotics and engineering kits
- Multimedia tools for digital storytelling and science communication

A shared online learning platform will be developed or adopted (e.g., Moodle, Canvas, or a custom LMS) to host synchronous and asynchronous modules, collaborative projects, and virtual mobility components.

Accessibility and inclusion will be prioritized by ensuring:

- User-friendly interfaces and multilingual content
- Captioned video lectures and screen-reader compatible documents
- Mobile access to course materials for learners in remote regions

Cloud-based tools (e.g., Google Workspace, Microsoft 365) will support real-time collaboration, virtual team teaching, and cross-institutional dialogue.

4. Institutional and International Collaboration: Creating a Networked Ecosystem

The joint Master's program aims to establish a networked community of practice across the consortium, fostering ongoing collaboration between partner universities, schools, industry, and research institutions.

Strategic activities will include:

- **Joint Faculty Teams**: Academics from each country will co-develop and co-deliver selected modules, fostering knowledge exchange and capacity building.
- **Cross-Campus Student Mobility**: Intensive Learning Weeks, STEM Camps, or Summer Schools will rotate among partner universities, offering students international exposure.
- **School Partnerships**: Agreements with local and regional schools will facilitate practicum placements, action research projects, and co-creation of teaching resources.
- **Industry and NGO Partnerships**: Engagement with private sector and civil society will support innovation labs, mentorship programs, and hackathons addressing societal STEM challenges.

In addition, partner institutions will jointly pursue opportunities for publication, conference participation, and Erasmus+ follow-up projects, ensuring the program becomes a catalyst for broader academic and professional engagement.

5. Monitoring, Evaluation, and Sustainability

To ensure quality, accountability, and impact, the Master's program will include a comprehensive Monitoring and Evaluation (M&E) framework, guided by formative and summative assessment principles.

Components will include:

- **Learning Outcome Mapping**: Regular assessment of student progress against program-specific learning outcomes using rubrics, portfolios, and reflective assessments.
- **Faculty Development Tracking**: Pre- and post-program evaluation of teaching competencies and innovation engagement among instructors.
- **Stakeholder Feedback**: Surveys, focus groups, and interviews with students, mentors, and school partners to inform iterative program improvement.
- **Impact Evaluation**: Measurement of graduate career pathways, classroom application of acquired skills, and institutional uptake of STEM innovations.

Sustainability strategies include:

- **Institutionalization** of the program as a permanent degree offering within each university.
- **Integration** into national STEM strategies and policy priorities.
- **Revenue generation** through continuing education formats and professional certifications.
- **Scalability** via online-only modules and future expansion to additional countries.

The strategic plan outlined here envisions the Master's program as more than a qualification-it is a transformative educational intervention that addresses long-standing challenges in STEM education across the region. By fostering innovation, inclusivity, and internationalization, the program aims to empower a new generation of STEM educators and educational leaders.

Through a shared curriculum, collaborative teaching, integrated infrastructure, and sustainable governance, the program will contribute to building a future-ready workforce, resilient learning systems, and stronger bridges between education, research, and society.

RECOMMENDATIONS

Based on the comparative analysis of national reports, identified challenges, and documented good practices, this section offers a structured set of recommendations aimed at facilitating the successful implementation, institutionalization, and long-term sustainability of the joint Master's program in innovative STEM strategies.

The recommendations are organized into three main levels:

- **Policy-Level Recommendations**: Addressing national and regional education authorities, policymakers, and ministries.
- **Institutional-Level Recommendations**: Targeting universities, teacher education faculties, and administrative bodies.
- **Program-Level Recommendations**: Aimed at the operationalization and continuous improvement of the joint Master's program.

A. POLICY-LEVEL RECOMMENDATIONS

1. Insert Interdisciplinary STEM Education into National Higher Education Frameworks

Policymakers in all partner countries should take active steps to integrate interdisciplinary STEM education into national teacher training standards and strategic education plans. This includes:

- Recognizing interdisciplinary STEM teaching as a formal competency.
- Developing funding frameworks that support cross-departmental and cross-institutional collaboration.
- Encouraging flexibility in academic accreditation systems to accommodate joint degrees and mobility across institutions.

2. Allocate Sustainable Public Funding for STEM Infrastructure and Professional Development

To achieve equity and long-term scalability, governments must move beyond project-based financing and commit to sustained investment in:

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

- STEM learning spaces, labs, and maker centers at universities.
- Continuous professional development (CPD) programs focused on digital pedagogy and sustainability.
- Financial support for faculty exchange and student mobility in STEM teaching programs.

3. Promote National and Regional Networks for STEM Educator Development

The creation of national platforms or consortia that bring together universities, schools, industry, and non-profits will:

- Facilitate the dissemination of good practices.
- Foster research-practice-policy dialogue.
- Enable coordinated responses to shared educational challenges.

Governments should incentivize participation in such networks through recognition, policy alignment, and research grants.

4. Ensure Equity, Inclusion, and Access in STEM Education Policies

STEM education strategies must explicitly address the needs of underrepresented and marginalized groups. This involves:

- Setting national targets for gender parity in STEM teacher training.
- Funding inclusive design initiatives for STEM resources and infrastructure.
- Encouraging localized outreach programs for rural and disadvantaged communities.

B. INSTITUTIONAL-LEVEL RECOMMENDATIONS

1. Establish University STEM Education Innovation Hubs

Each partner institution should designate or create a STEM Education Innovation Hub, responsible for:

- Piloting new teaching models and technologies.
- Coordinating practicum placements and partnerships with schools.
- Hosting interdisciplinary teams of faculty, researchers, and students.

These hubs can serve as incubators for curriculum reform and pedagogical research.

2. Integrate Faculty Development Programs on STEM Pedagogy

STEM education reform depends on instructors being well-prepared to adopt innovative teaching approaches. Universities should:

- Mandate ongoing professional development in STEM pedagogy as part of academic career progression.
- Provide training in student-centered teaching, digital tools, and sustainability integration.
- Support peer mentoring and collaborative course design across faculties.

The proposed Master's program should itself be co-taught by interdisciplinary faculty teams who model effective practice.

3. Foster Collaboration Between STEM Faculties and Education Faculties

To overcome the walls in higher education, institutions should:

- Align science and education faculty curricula where teacher preparation is concerned.
- Encourage co-teaching and team supervision of student projects.
- Establish formalized collaboration structures such as joint advisory boards or shared research centers.

4. Strengthen Partnerships with Schools, NGOs, and Industry

Real-world relevance is essential to preparing future STEM educators. Universities should:

- Sign cooperation agreements with primary and secondary schools for practicum and field research.
- Engage industry partners in mentoring, guest lectures, and innovation challenges.
- Involve NGOs in co-developing socially relevant STEM education projects (e.g., climate action, gender equity, digital literacy).

These partnerships not only enhance program quality but also foster a sense of civic and global responsibility among students.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

C. PROGRAM-LEVEL RECOMMENDATIONS

1. Design a Modular and Flexible Curriculum

The Master's program must accommodate diverse learners and local needs. This requires:

- Modular course structures that allow for customization and specialization.
- A mix of synchronous and asynchronous learning activities.
- Cross-cutting themes such as inclusion, sustainability, and digital fluency embedded in every module.

Partner universities should co-develop a core curriculum with optional specialization tracks tailored to national or regional priorities.

2. Implement Practice-Based and Research-Integrated Learning

To develop effective STEM educators, learning should be anchored in:

- Authentic school-based experiences and problem-solving projects.
- Collaborative research on teaching innovations and STEM applications.
- Integration of design-based research or action research into final theses.

Students should graduate with a portfolio of field-tested pedagogical tools, lesson plans, and reflective case studies.

3. Use Technology as an Enabler, Not a Substitute

Digital tools should enhance-not replace-human interaction and critical engagement. Program developers should:

- Select technology based on pedagogical purpose (e.g., VR for immersive science, data tools for inquiry).
- Train students and instructors in effective, ethical use of edtech.
- Evaluate the accessibility and inclusivity of selected tools for all learners.

Virtual exchanges, simulations, and international collaboration spaces should complement onsite activities.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

4. Establish Clear Assessment and Quality Assurance Mechanisms

Assessment should be multidimensional, focusing on:

- Competency development across cognitive, technical, and social domains.
- Formative assessments (e.g., reflective journals, peer reviews) alongside summative tasks.
- Feedback from mentors, school partners, and faculty to ensure holistic evaluation.

Quality assurance should include both internal reviews and external validation by academic peers and stakeholders.

5. Build a Strong Alumni and Knowledge-Sharing Community

To ensure long-term impact, the program should:

- Create an alumni network to foster ongoing collaboration, mentorship, and resource exchange.
- Host annual STEM education conferences, webinars, or online forums.
- Publish open-access teaching resources, case studies, and research findings to extend the reach of project outcomes.

Graduates of the Master's program should be empowered as multipliers and change agents within their institutions and communities.

The successful implementation and sustainability of the Erasmus+ joint Master's program depend on a shared commitment to innovation, collaboration, and social impact. These recommendations provide a strategic roadmap for aligning national policy, institutional structures, and program design with the evolving demands of STEM education in the 21st century.

By acting on these recommendations, partner countries can not only enhance their teacher training systems but also contribute meaningfully to the broader goals of the European Education Area-equity, quality, digital transformation, and sustainable development. The joint Master's degree is not only an academic offering; it is a vehicle for systemic change and a model for future transnational cooperation in higher education.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

CONCLUSION

The development and implementation of a joint Master's program in Integrating Innovative STEM Strategies in Higher Education represent a timely and transformative response to the growing educational, economic, and social demands of the 21st century. The findings from Bulgaria, Serbia, Türkiye, and Uzbekistan confirm a collective awareness of the strategic importance of STEM education. At the same time, they reveal systemic challenges that require coordinated efforts, visionary leadership, and innovative pedagogical solutions.

This transnational report has provided a thorough comparative analysis of the current state of STEM education in the partner countries. It identified critical areas such as fragmented policy implementation, rigid and theory-heavy curricula, faculty training deficits, infrastructure disparities, weak links between research and teaching, and barriers to equitable participation. These challenges are not unique to one country but reflect wider regional and global concerns, thus underscoring the relevance of a shared, transnational approach.

At the same time, the report documents a wide array of promising practices that can inform and inspire program design. These include the expansion of STEM centers, the integration of green and digital competencies, student-centered pedagogy, and interdisciplinary curriculum models. Across the four countries, educators and institutions are experimenting with new ways of teaching and learning that break disciplinary boundaries, connect with real-world challenges, and empower students to become active learners and innovators.

The proposed Master's degree, shaped through collaborative curriculum design and grounded in the shared expertise of the project consortium, is positioned as a catalyst for change. It aspires to prepare future educators not only to teach STEM subjects more effectively but also to lead reform in their institutions and communities. Through a modular, interdisciplinary, and digitally supported structure, the program will be accessible, adaptable, and globally relevant. Its grounding in sustainability, innovation, and inclusivity will ensure it addresses both present needs and future opportunities.

The strategic plan and recommendations outlined in this report provide a clear roadmap for the next stages of implementation. From aligning national policies to institutionalizing teacher education reforms, from empowering faculty to integrating field-based research, the program offers a systemic and sustainable response to the evolving expectations of higher education. The recommended actions are adaptable across varied national contexts and institutional cultures.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2
Project Reference: 2024-1-BG01-KA220-HED-000253761

Ultimately, this report is not just an academic deliverable - it is a call to action. It calls on policymakers to invest in transformative teacher education. It calls on universities to break down barriers and foster collaboration. It calls on educators to embrace change, lead innovation, and champion inclusivity. And it calls on students to become not just consumers of knowledge but creators of change.

As the project advances into the next phase-piloting, implementation, and evaluation - the insights and commitments reflected here will serve as the foundation for impactful, enduring, and forward-looking STEM education across Europe and Central Asia.

This Programme is funded by the European Union Erasmus+ KA220-HED - Cooperation partnerships in higher education Call 2024 Round 1 KA2

Project Reference: 2024-1-BG01-KA220-HED-000253761