Secondary School Physics Education in the Balkans: Challenges, Perspectives and Pathways Toward a Sustainable STEM Future

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Abstract. Physics education across the Balkan region faces persistent challenges related to student engagement, gender imbalance, and the alignment of science education with contemporary societal and technological developments. In several countries, fewer than 10% of secondary school graduates pursue studies in physics or engineering, and women represent only 20–30% of this already limited cohort. These trends raise concerns regarding long-term scientific capacity, innovation potential, and inclusive participation in the green and digital transitions. This paper presents an exploratory qualitative analysis of secondary school physics education in selected Balkan countries. Rather than offering a comparative quantitative review of national curricula, teaching hours, or system-level indicators, the study draws on expert testimonies from long-standing representatives of the Balkan Physical Union (BPU) and insights gained through the international Youth@STEM4SF pilot initiative. Using thematic analysis of practitioner perspectives, the paper identifies recurring patterns perceived across different national contexts. The findings point to concerns regarding predominantly theoretical teaching approaches, limited access to experimental and inquiry-based learning environments, insufficient structural support for teachers, and weak connections between physics education, industry, and real-world applications. These factors are reported by practitioners as contributing to student disengagement and reinforcing perceptions of physics as abstract or inaccessible—particularly among girls. At the same time, the analysis highlights the limited availability of harmonised regional data on STEM education indicators, underscoring the need for more systematic comparative research to support evidence-based reform. The paper discusses how interdisciplinary, project-based initiatives such as Youth@STEM4SF—piloted in Switzerland and introduced through regional cooperation—may offer context-adaptable approaches to strengthening relevance, sustainability orientation, and cross-border collaboration in science education. Beyond educational considerations, reinforcing physics education in the Balkans is framed as contributing to gender equity, innovation ecosystems, and regional scientific dialogue in a historically sensitive context.

1 Introduction

Physics education across the Balkan region is confronted with persistent and complex challenges that affect both the quality of teaching and student engagement. Despite being a foundational discipline within the natural sciences, physics attracts a critically low number of students to pursue it further in higher education. In most Balkan countries, fewer than 10% of secondary school graduates go on to study physics or engineering at the university level. Of this small group, only 20–30% are female, reflecting a significant gender gap that continues to resist efforts toward greater inclusion in STEM (science, technology, engineering, and mathematics). Low confidence of female students and high drop-out rates (for example ~ 50% in Montenegro) are important issues.

Several factors contribute to this disinterest in physics and broader STEM fields. High school physics curricula are often highly theoretical and disconnected from practical applications, making it difficult for students to see the relevance of the subject. Crucially, many Balkan education systems still lack interdisciplinary programs that integrate STEM disciplines, such as biophysics, bioengineering, or computational biology, missing opportunities to illustrate how science functions in todays interconnected world.

This disconnect has broader implications. The absence of modern, interdisciplinary content contributes to persistently low scores on international assessments like PISA, reflecting gaps not just in knowledge but in critical thinking and problem-solving. While technology initiatives like "One Laptop/Tablet per Child" are often discussed, they remain largely absent in practice - and even when devices are available, they are no substitute for quality educational content. As the saying goes, "the laptop/tablet is not the strength; it is the content that's the strength." Without investment in meaningful, integrated STEM curricula, like initiative Youth@STEM4SF [1] showcases, the region risks falling further behind in cultivating a scientifically literate and innovative next generation.

Physics education teaching methods are perceived by many practitioners as outdated. Moreoever, limited access to laboratory facilities, and insufficient teacher training compound the problem. Moreover, students often lack exposure to real-world applications and career opportunities in physics-related fields, especially within the regional context. The broader societal undervaluation of science professions, coupled with economic instability, further disincentivizes students from choosing STEM paths.

These challenges have broader implications. According to testimonies collected from BPU representatives, traditional teaching methods are perceived as limiting opportunities for innovation potential and hindering the development of STEM literacy among youth. Cross-border collaboration and networking opportunities for students interested in STEM are also rare. This is especially relevant in the Balkans, where scientific collaboration can support peacebuilding and regional cooperation. Projects like SEEIIST [2] - modelled after CERN and focused on cancer research - highlight the power of science diplomacy and multidisciplinary STEM synergy. By uniting experts from fields like physics, biology, engineering, and medicine, SEEIIST shows how breaking disciplinary boundaries can drive innovative solutions to urgent health challenges.

This paper outlines the current state of physics education in the Balkans and identifies systemic barriers within secondary STEM education. It argues for a coordinated, cross-national effort to modernize and strengthen science teaching, drawing on insights from both Balkan stakeholders and Swiss STEM education experts. The analysis is structured around several guiding questions that emerged from recent dialogues:

- What proportion of high school graduates pursue university studies in physics and engineering in each country, and what percentage of these students are female?
- What are the root causes of low student interest—are there identifiable gaps in high school science education?
- What methods and interventions have proven effective in raising interest, and how can they be better integrated into classrooms?
- What are the current trends and planned actions to embed sustainable development into science teaching?
- To what extent are physics-based industries involved in high school education, and how can these links be strengthened?
- What governance structures and stakeholders are needed to initiate and sustain reforms in science education across the Balkans?

By addressing these questions by experts on education and outreach from countries represented by Balkan Physics Union BPU [3], the paper seeks to support policy innovation and foster collaborative regional responses that can shape a more inclusive and future-ready STEM education system in the Balkans - following international pioneering STEM education trends successfully piloted in other countries, such as Switzerland [1,4,5].

The analysis presented in this paper is based on qualitative inputs collected between 2023 and 2024 through structured discussions, informal interviews, and written testimonials from representatives of the Balkan Physical Union (BPU), physics educators, and stakeholders involved in the Youth@STEM4SF initiative. These contributors have long-standing professional experience with secondary education systems in their respective countries. In addition, observations from the design and implementation of the Youth@STEM4SF international pilot were used to identify recurring challenges and opportunities related to physics teaching, student engagement, and innovation-oriented STEM education. The authors acknowledge that harmonized, publicly available comparative data on physics curricula, teaching hours, laboratory infrastructure, and teacher training systems across the Balkan region are limited. Consequently, this paper does not aim to provide a comprehensive comparative analysis of national education systems, but rather an expert-informed, exploratory perspective grounded in practitioner experience. This limitation also motivates the paper's recommendation for improved regional data collection and systematic evaluation in future work.

2 Balkans: Challenges and Perspectives in Secondary School Physics Education

2.1 Share of Secondary School Graduates Entering Physics and Engineering Programs

Compared with the rest of the European Union, the Balkan region is no exception in showing relatively low student interest in STEM fields. However, for post-conflict and transition economies in the region - some of which are still classified by international institutions such as the ICTP [6] as developing countries - strengthening science and technology education is particularly crucial. Preparing for the Fourth Industrial Revolution requires strategic investment in human capital, innovation, and competitiveness, as well as a special effort to foster a new generation of scientists and engineers capable of driving sustainable growth.

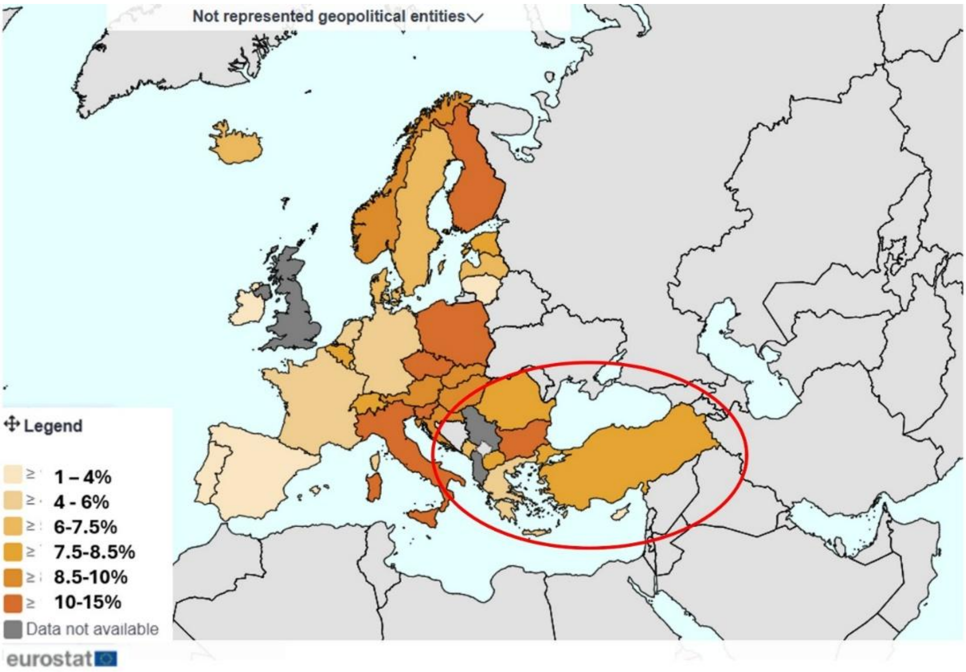

Fig 1: Students in Europe enrolled in STEM education fields - per thousand of population aged 20-29. Focus on Balkan countries in the area in circle with Slovenia and Bulgaria with highest numbers.

Even though Slovenia and Bulgaria show a growing interest in STEM fields, along with improved gender equality (see Fig. 1 and Fig. 2), their positive trend still represents an exception within the broader regional context. In Slovenia, for instance, growth in STEM enrolments reported in 2024 compared with the previous academic year, with the largest increase observed in natural sciences, mathematics, and statistics - by 4.0%.

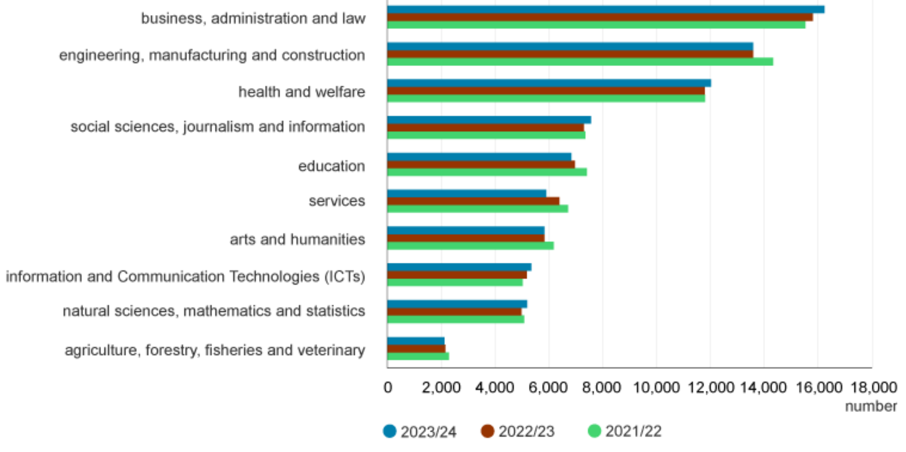

Fig 2: Students by tertiary education by field in Slovenia, KLASIUS-P-16, Eurostat.

However, on a broader scale across the Balkan region, a major challenge remains the shortage of educational science programs and future STEM educators - a factor crucial for long-term development, innovation, and economic competitiveness. In most Balkan countries, fewer than 10% of high school graduates pursue university degrees in physics or engineering. In Serbia and Croatia, approximately 7–9% of students choose technical or natural sciences. In Montenegro, although overall enrolment in STEM fields reaches 20–25%, participation in physics is much lower - around 5%. Similarly, in Bosnia and Herzegovina and North Macedonia, the share is approximately 5–6%, with physics among the least selected majors. In Albania, only 2% of students choose natural sciences (see Fig. 3).

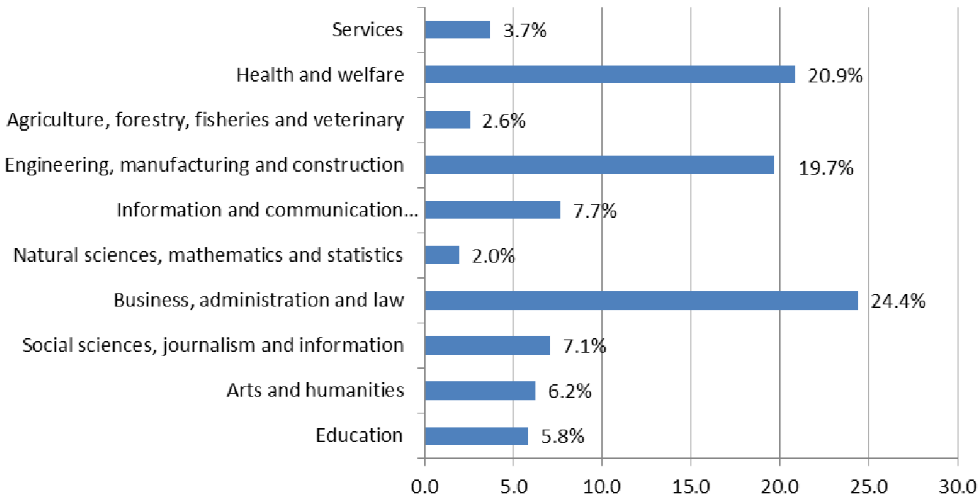

Fig.3. Percentage distribution of the number of students enrolled in tertiary education by field of study, 2023-24, Source: INstitute of STATistics of Albania

This pattern is reflected across much of the Balkan region, where interest in physics and engineering remains modest despite the growing need for STEM professionals and educators. In Greece, only about 10–12% of high school graduates pursue university degrees in physics, engineering, or other technical sciences - figures comparable to those of neighboring countries. In Cyprus, although 75–80% of high school graduates continue to tertiary education (among the highest rates in the EU), many students study abroad, mainly in Greece, the UK, or other EU countries, due to limited domestic capacity. Within the country, only 8–10% of tertiary students specialize in engineering and just 1–2% in physics or pure sciences, with a clear preference for medicine, pharmacy, and business-related programs.

In Montenegro, the problem is further compounded by a shortage of qualified STEM educators, particularly in rural areas. Despite relatively high overall enrolment in STEM fields (20–25%), the system continues to face difficulties in staffing schools with trained teachers in mathematics, physics, chemistry, and biology. This shortage contributes to a broader lack of motivation among students to pursue STEM pathways, perpetuating a cycle of limited interest and inadequate educational capacity across the region.

2.2 Gender Representation in STEM: Persistent Gaps and Emerging Hope

Across the Balkans, gender disparity in STEM remains a persistent challenge. In physics, women make up less than 30% of students in most countries, while in engineering, the share of female students generally ranges between 15–25%, depending on the field. As noted by the Western Balkans InfoHub [7], "women outnumber men in university education, yet they remain strikingly under-represented in Science, Technology, Engineering and Mathematics (STEM) careers." Similarly, the UNDP report "Advancing Women in STEM in the Western Balkans" [8] emphasizes that despite women's equal academic performance, their participation in higher education STEM programs continues to lag behind that of men.

This imbalance is particularly evident in Montenegro, where the University of Montenegro - the only public higher education institution with about 21,600 students - shows a clear gender divide across faculties. While women account for 70% of students in Economics, their representation in engineering remains low: 13% in Mechanical Engineering, 19% in Electrical Engineering – Electronics, 5% in Electrical/Automation, and 47% in Civil Engineering. Overall, female participation in physics and engineering is well below 20%. This underrepresentation is compounded by high dropout rates, as only 47–51% of students complete higher education in physics and related fields. As seen across the region, gender stereotypes continue to influence career choices- many girls perform well in science but lack confidence in physics, which discourages them from pursuing STEM degrees.

A similar pattern is visible in Greece, where fewer than 30% of physics students are female, and in engineering, women represent only 20–25% of enrolments depending on the specialization.

In Cyprus, where women represent over 55% of all university students, the gender gap in STEM is less severe but still present: 30–35% of engineering students and 40–45% of physics students are women. Despite high tertiary participation and international mobility, Cypriot students - both male and female - continue to show a preference for medicine, pharmacy, and business over hard sciences.

	Number of students placed in higher education departments related to physics and engineering in 2024			Number of currently enrolled students in higher education departments related to physics and engineering		
Gender	Male	Female	Sum	Male	Female	Sum
Sum	69508	38529	108037	347303	160641	507944
%	64,3%	35,7%	100%	68,4%	31,6%	100%

Fig.4: Findings about higher education departments related to physics and engineering obtained from the 2024 university entrance exam data and universities database of Turkey

The situation in Turkey reinforces this broader regional trend. According to the 2024 university entrance exam data and the national universities database, physics- and engineering-related fields in Türkiye exhibit a clear gender imbalance. Male students account for 64.3% of newly placed students and 68.4% of currently enrolled students, while women represent only 35.7% of new entrants and 31.6% of total enrolments. This indicates a persistent male dominance in physics and engineering, suggesting that women remain significantly underrepresented in these disciplines, possibly reflecting structural, cultural, or motivational barriers that discourage their participation and continuation in such fields.

Amid these challenges, Bulgaria stands out as an inspiring example of progress and inclusion. According to Eurostat [9], women make up a majority of scientists and engineers in Bulgaria, representing 51–54% depending on the year - an improvement in female participation since 2018. This positive trend reflects targeted investments in STEM education and gender-inclusive national policies. Initiatives such as the establishment of national STEM centres, focused on hands-on learning and teacher training, highlight Bulgaria's commitment to gender parity and its leadership role within the Balkans. The country's progress demonstrates the diversity and potential of the region - and offers a model of hope for advancing gender equality and innovation in STEM education across Southeastern Europe.

2.3. Root Causes of Low Student Interest in STEM: Identifiable Gaps in High School Science Education

The low interest in STEM studies across the Balkans and surrounding regions can be traced to several interrelated educational and societal factors. As observed by BPU representatives, the curricula that do not yet contain the modern physics and approaches, often emphasize rote memorization over conceptual understanding, leaving students disengaged and struggling to see the relevance of science in everyday life. Many schools lack modern laboratory infrastructure, which limits opportunities for practical experiments and hands-on learning. This problem is compounded by a historical underinvestment in lab-based teaching and insufficient teacher training in interactive, interdisciplinary, or inquiry-based pedagogy. Furthermore, career visibility in STEM - especially in physics - is limited, making the field seem abstract or irrelevant. Gender stereotypes continue to discourage girls from choosing physics or engineering, and students frequently perceive STEM subjects as harder than others. Low confidence in mathematics and natural sciences by females has been repeatedly reported, which further reduces their interest in pursuing science-based careers. These challenges are reinforced by a lack of integration between education, labour markets, and innovation ecosystems across the region.

In Montenegro, such challenges are evident and strongly quantified. The system faces high dropout rates, with a STEM higher education completion rate of approximately 47–51%, illustrating persistent disengagement across the learning pathway. Teaching methods remain outdated, offering limited opportunities for problem-solving and interactive learning, which weakens student motivation and understanding of science concepts. As in other Balkan contexts, gender stereotypes are evident: girls perform well academically but have lower confidence in physics, resulting in fewer pursuing STEM degrees. At the same time, there is a high demand for teachers in mathematics, physics, chemistry, and biology, yet the education system continues to struggle with staffing, particularly in ensuring a sufficient number of qualified STEM educators.

In Greece, the root causes mirror those observed across the Balkans. The education system still relies heavily on outdated curricula and rote-based teaching, with limited access to laboratories and few opportunities for experimentation or project-based learning. Science subjects are often presented without real-world context, reinforcing the perception that physics and engineering are abstract or disconnected from students' lives. As in other regional cases, gender stereotypes persist, and teacher training in modern pedagogical approaches remains limited. This combination of structural and cultural barriers continues to dampen student motivation to pursue STEM degrees.

In Albania, both educational and socio-economic factors contribute to the low appeal of physics and STEM disciplines. On the educational side, students often perceive physics and mathematics as too abstract or difficult, while outdated teaching methods and limited access to laboratories or modern tools further reduce engagement. A shortage of qualified STEM teachers, particularly in rural areas, undermines the consistency and quality of instruction. In addition, career guidance in schools is minimal, and few programs connect STEM learning with real-world or local job opportunities. Economic and social factors deepen these challenges. Salaries in STEM professions are often lower than in law or business, and many talented graduates choose to emigrate in search of better educational or professional prospects. The lack of national research infrastructure, including R&D centers and technology hubs, limits opportunities for innovation and inspiration. As a result, many students view STEM as irrelevant to Albania's domestic job market, perpetuating a cycle of disinterest and brain drain. This is valid for other countries in the region.

In Cyprus, the situation reflects similar systemic weaknesses. Science education remains largely theoretical and rote-based, with insufficient hands-on experiments and projects, and weak links between scientific concepts and real-world applications. The integration of ICT, robotics, and engineering principles into the school curriculum is still limited, which restricts students' exposure to modern STEM fields. Perceptual and social barriers also persist: STEM careers are often viewed as difficult and uncertain, while gender norms discourage girls from pursuing engineering. Moreover, career counselling and industry outreach remain underdeveloped, leaving students with little awareness of the opportunities available within the local or European STEM labour market.

Across all these countries, the root causes of low student interest in STEM stem from a combination of outdated educational practices, limited infrastructure, and weak career linkages, reinforced by social and economic factors such as gender stereotypes, low salaries, and emigration of talent. Addressing these interconnected challenges - through modernized curricula, better-trained teachers, improved lab facilities, and visible career pathways - remains essential for fostering a new generation of scientists and engineers capable of driving sustainable innovation across the region.

2.4. Methods and interventions proven effective in raising interest in physics and STEM

Methods that have proven effective in increasing student interest include project-based learning that links physics and other sciences to real-world applications, STEM competitions such as science fairs and robotics challenges, as well as the use of role models and mentoring programmes. Partnerships with universities and industry - for guest lectures, laboratory visits, and collaborative projects - further enhance student motivation. The use of digital simulations and virtual laboratories has also shown strong results, especially in schools where access to equipment is limited. High schools that place greater emphasis on practical, hands-on learning and teamwork consistently report a higher proportion of students choosing STEM-related careers.

To integrate these methods effectively into classrooms, national education strategies should mandate hands-on science projects, offer continuous professional development for teachers in modern pedagogical techniques, and promote systematic collaboration between schools, universities, and industry.

In Montenegro, several promising interventions have emerged to strengthen student engagement in STEM. Gender-sensitive programmes have contributed to improving girls' participation and confidence in science and engineering. Although Bologna-style reforms and credit systems are being followed, the practical learning opportunities remain limited, highlighting a persistent gap between policy and classroom practice. In cooperation with the

University of Montenegro, the Government of Montenegro established the Science and Technology Park on the university campus to foster closer connections between education and industry. The university also runs multidisciplinary STEAM programmes, which serve as an encouraging example of innovation in STEM education. However, these initiatives still represent isolated efforts rather than part of a comprehensive national strategy.

In Greece, similar initiatives have proven successful in sparking student interest. STEM fairs, Olympiads, university outreach activities, and the growing use of digital platforms and virtual laboratories have provided engaging, hands-on experiences for students. Yet, to achieve lasting impact, these efforts must be expanded nationwide and supported by systematic teacher training and curriculum reform that embeds practical and project-based learning at the core of science education.

In Albania, recent reforms and international partnerships reflect growing recognition of the importance of strengthening STEM education. Under the Government Strategic Plan (2021–2025), significant investments have been directed toward modernising school infrastructure, including the development of STEM laboratories in high schools to promote hands-on learning. Efforts also focus on teacher training and recruitment, with particular attention to upskilling existing educators and hiring specialised staff in rural areas. In parallel, EU-supported programmes (e.g. IPA 2024–2027 funding framework) aim to enhance digitalisation, innovation, and human capital, with a dedicated focus on STEM promotion. Initiatives such as the Albanian Academic Network (RASH) are helping to strengthen research collaboration and open science. Complementing these policy efforts, NGOs and private partners, including STEM Outreach Albania and the Space Generation Advisory Council (SGAC), run hands-on workshops, school visits, and student competitions, such as NASA-inspired challenges, to inspire young people's interest in physics, space science, and technology.

2.5. Current trends and planned actions to embed sustainable development into science teaching

The integration of Sustainable Development Goals (SDGs) into national curricula is gradually increasing across the Balkan region, though progress remains uneven. Some countries have begun piloting environmental modules within physics and chemistry classes - covering topics such as renewable energy and water conservation - to connect scientific concepts with real-world sustainability challenges. NGOs and international organisations, including UNESCO, GIZ (German Agency for International Cooperation), and the British Council, make efforts to support these efforts by linking science education with climate action and green technologies. These efforts, however, stay limited without national coverage. While a few schools explicitly identify sustainable development as part of their educational mission, these remain isolated cases, and sustainability themes have yet to be systematically integrated into regular science curricula.

In Greece, environmental education is formally included in the national curriculum and supported by a range of EU- and NGO-funded initiatives. However, the integration of sustainability concepts into core physics and STEM subjects remains limited. Greater emphasis is needed on embedding SDG-related competencies—such as systems thinking, energy literacy, and environmental responsibility—directly into science teaching and learning outcomes.

Across most Balkan countries, there are still no specific national initiatives that explicitly embed sustainable development within science education. Nevertheless, a regional trend is emerging toward addressing foundational educational barriers, particularly through early interventions that challenge entrenched stereotypes - such as the belief that "girls aren't good at physics." To build on this momentum, ministries of education should take more active measures to integrate sustainability competencies into science curricula and to promote interdisciplinary STEM projects that engage students with pressing global challenges, especially those related to climate change, renewable energy, and the circular economy.

2.6. Involvement of Physics-Based Industries in High School Education and Recommendations for Strengthening Collaboration

At present, industry involvement in high school science education across the Balkans remains limited and fragmented, often depending on local initiatives or the personal networks of individual teachers. Such partnerships tend to be sporadic rather than systemic, as heavy workloads and administrative constraints leave educators little time to establish or maintain external collaborations.

To strengthen these links, national frameworks for school–industry cooperation are needed to ensure consistency and long-term sustainability. Schools could offer internships, company visits, or dedicated "science days" in collaboration with physics-based industries, giving students direct exposure to applied science and technology. Industry experts should also be involved in curriculum design and mentorship programmes, helping to bridge the gap between classroom learning and real-world practice. Furthermore, public–private partnerships could play a crucial role in equipping schools with laboratory tools and modern resources. Coordination through central institutions - such as Chambers of Commerce or Craft and Small Businesses - would help standardise these efforts and make them accessible to a broader range of schools.

In Greece, for example, the collaboration between physics-based industries and schools is stronger in urban areas, particularly around Athens and Thessaloniki, but remains limited at the national level. Expanding initiatives such as internships, guest lectures, and company visits could significantly enhance student awareness of STEM careers. Greater alignment with national education strategies and access to EU funding instruments would help scale these partnerships and ensure more equitable outreach across regions.

In Albania, the industry–education gap persists despite growing efforts to connect the two sectors. A notable example is Tirana Innovation Week, an annual event that features workshops, technology exhibitions, industry panels, and networking activities designed to promote STEM among young people and foster dialogue between education, research, and business.

Such initiatives represent an encouraging start but remain isolated; long-term success will depend on embedding these partnerships into formal national frameworks and expanding opportunities for student participation in real-world innovation environments.

2.7. Governance Structures and Stakeholders Needed to Sustain Reforms in Science Education

The current moment presents a critical opportunity to modernize STEM teaching and strengthen its relevance across the Balkan region. Achieving lasting reform requires a multi-level governance approach that combines national policy direction with local implementation and stakeholder engagement. Stronger governmental support - particularly in financing teacher education, both pre-service and in-service - is essential to ensure the long-term quality and continuity of science instruction. Better content-related support for teachers is also needed, alongside measures to increase the number of qualified educators entering the profession. In parallel, governance structures should enable more systematic connections between schools, industry, and research institutions, providing teachers with access to practical expertise and collaboration opportunities. National and regional bodies should also support student and teacher innovation projects - for instance, engineering challenges such as building a submarine -carried out in partnership with local industries.

The experience of Montenegro illustrates both progress and remaining challenges. Higher education reform is overseen by the Council of Higher Education, but quality assurance mechanisms remain weak, and degree completion rates are low while dropout levels are high, signalling insufficient student preparedness and institutional support. To address these issues, the Ministry of Education has great opportunity to build on existing partnerships, such as with the Science and Technology Park, to implement teacher training programmes in collaboration with industry and to strengthen the continuum between secondary and higher education governance.

In Greece, reforms in science education are governed centrally, which provides consistency but can also slow progress and limit flexibility. A multi-stakeholder governance model - involving universities, industry representatives, students, and NGOs - would allow for more dynamic reform processes. Policies should be context-sensitive and data-driven, ensuring that national strategies are adapted to local needs and grounded in evidence from educational outcomes and labour market trends.

In Albania, governance priorities centre on curriculum and assessment reform. Modernising the physics curriculum to align with PISA standards and incorporating more inquiry-based and practical learning elements are key steps toward improving science literacy and engagement. The planned Matura exam reform, which aims to introduce STEM-focused modules and real-world problem-solving tasks, represents a promising direction for evaluating students' applied understanding of physics. Strengthening public–private partnerships is equally important: establishing contracts between universities, businesses, and R&D centres would create opportunities for hands-on internships, mentoring, and direct industry experience for STEM students.

Overall, sustainable science education reform in the Balkans depends on inclusive governance structures that connect policymakers, educators, industry, and civil society. Building these networks will be vital for aligning educational objectives with innovation needs and for ensuring that science education becomes both high-quality and socially relevant across the region.

2.8. Teacher Training and Reskilling for Interdisciplinary STEM Education

Across the Balkan region, a major challenge in advancing modern STEM education lies in the high specialization of secondary school teachers. In most cases, STEM educators are trained narrowly within a single discipline - for instance, a physics teacher often holds only a BSc in general physics and therefore lacks the cross-disciplinary expertise needed to integrate concepts from biology, engineering, or computer science. This situation, exemplified by the case of Slovenia, is common throughout the region and reflects a broader structural issue in teacher education systems.

To overcome this limitation, greater institutional and policy support is needed for interdisciplinary teacher development. Universities and teacher training colleges should introduce interdisciplinarity as a core component of pre-service education, ensuring that future teachers can design and deliver lessons that connect multiple STEM domains. Concrete training priorities include STEM integration courses focused on creating interdisciplinary and inquiry-based lessons; digital pedagogy, such as the use of simulations, data analysis, and virtual experiments; and entrepreneurship in science, encompassing innovation thinking, prototyping, and business planning. In addition, environmental science and sustainability should be embedded as cross-cutting themes, linking classroom learning to real-world challenges and the Sustainable Development Goals (SDGs).

In Greece, as an example for other countries, similar needs have been identified. There is a recognized gap in ongoing professional training for teachers in areas such as STEM integration, digital tools, entrepreneurship, and environmental education. These domains remain underrepresented in formal teacher education programmes, limiting the capacity of educators to implement interdisciplinary and problem-oriented teaching. Expanding professional development frameworks and embedding continuous training opportunities would allow teachers to better adapt to the evolving interdisciplinary nature of STEM and to inspire students to connect science learning with innovation and sustainability.

2.9. Including Student Voices in the Design of Future-Oriented Science Curricula

Across the Balkan region, student participation in curriculum design remains limited, despite the growing recognition that engaging young people in educational reform enhances both relevance and motivation. In many countries, students participate through student parliaments, which theoretically provide a channel for expressing their views. However, in practice, their influence is often minimal - comparable to that of teachers, whose voices are also not strongly integrated into decision-making processes. Encouraging student co-creation in science education reform would not only improve the alignment of curricula with learners' interests and future skill needs, but also foster greater engagement, ownership, and accountability among students.

Effective mechanisms for student participation could include national youth science panels that advise ministries of education, school-level science councils providing structured feedback on science-related activities, and online platforms or surveys that gather student suggestions for curriculum updates. Furthermore, students could be invited to participate in pilot curriculum projects as co-designers, contributing directly to the development and testing of innovative teaching approaches.

As reported from Greece, as a good example representing the region, the student participation in curriculum design remains minimal. While national educational reforms have introduced consultation processes, these rarely include structured input from students themselves. Establishing student science councils, national forums, and regular online consultation mechanisms would provide meaningful channels for youth input. Including students in pilot programs for science curriculum innovation could also help ensure that educational reforms remain relevant, inclusive, and future-oriented.

3. Towards a Transversal Model for Transforming STEM and Science Education in the Balkans

The analysis across Balkan and neighbouring countries demonstrates that while challenges persist - from physics curricula perceived as not enough up-to-date regarding the current physics knowledge and modern teaching methodologies, and gender gaps to weak school–industry collaboration - there is also a growing awareness of the need to modernize science education to meet the demands of the 21st century. Sustainable reform requires a transversal approach, integrating STEM, sustainability, innovation, and social inclusion across education systems. This means going beyond isolated reforms in physics or engineering and instead building interdisciplinary learning ecosystems that connect students, teachers, researchers, and industry under a shared vision of sustainable development and digital transformation.

One promising example of such an integrated model is the pioneering initiative Youth@STEM4SF (Youth at STEM for Sustainable Future) [**Error! Bookmark not defined.**,**Error! Bookmark not defined.**,**Error! Bookmark not defined.**] developed under the framework of the UNESCO International Decade of Science for Sustainable Development (2024–2033) in partnership with the Swiss Physical Society (SPS), and Swiss educational authorities, Big Science Business community and other important partners. This innovative program introduces high school students to physics and STEM subjects through real-life applications, sustainability challenges, and encounters with inspiring role models from academia and industry. Programme promotes transversal education by linking STEM learning to sustainability, ethics, and societal impact. It enables students - particularly girls - to engage in hands-on research, innovation challenges, and community-based projects addressing real-world issues such as climate change, clean energy, health and biodiversity protection. By connecting schools with universities, laboratories, NGOs, and private sector partners, Youth@STEM4SF demonstrates how collaborative, inquiry-based education can strengthen both scientific literacy and civic responsibility. Recently, the program has been approved as the official initiative for transversal education of the main network of the UNESCO International Decade of Sciences for Sustainable Development, the Earth-Humanity Coalition [10], where leaders and visionaries connect the dots to make positive changes for the world.

Fig.5. Youth@STEM4SF in pictures Switzerland 2023 – 2024

The project connects physics to pressing societal needs, such as climate change, energy, medical technologies, and environmental protection, by offering thematic days that include interactive talks and visits to tech industries and actors of innovation ecosystem; scaled up by student competition on the co-creation of new education materials connecting natural sciences with sustainable development. The most promising ideas from students are co-developed into digital teaching resources aligned with official education strategies. A majority of participating students, especially girls, reported a significantly increased interest in STEM fields, citing the visibility of relatable role models and societal relevance as key motivational factors. By fostering a network of engaged students, teachers, scientists, and policymakers, Youth@STEM4SF aims to reform how STEM is taught and perceived. It strengthens links between science education and sustainable innovation ecosystems, helping to mitigate brain drain and build a new generation of informed, empowered leaders. Moreover, the project represents science diplomacy in action, engaging education authorities to support its implementation and contributing to the transformation of high school STEM education at the national level.

Successful Swiss pilot and proof of concept since 2023 has been extended to Slovenia during the dedicated pre-event of Big Science Business Forum 2024 in Trieste [11]. More then 100 Slovenian students from 3 high schools were inspired and participated in the competition with awards during dedicated satellite event of International Union of Pure and Applied Physics [12] at Big Science Business Forum. Several stakeholders from research community in Balkans are currently making efforts to bring the Swiss brand of Youth@STEM4SF to Central East European region and to expand the project to the Balkans during the UNESCO International Decade of Science for Sustainable Development (2024–2033) [13].

Fig 6: First out-of-Switzerland Youth@STEM4SF edition at Big Science Business Forum 2024, in Trieste with Slovenian schools from Ljubljana**.**

As a scalable and replicable framework, Youth@STEM4SF offers a pathway for systemic change in science education across the Balkans. It aligns educational content with the Sustainable Development Goals (SDGs) and the EU's Green Deal priorities, while empowering young people to see themselves as active contributors to societal progress, not just passive learners. Its methodology - rooted in interdisciplinarity, inclusivity, and collaboration - responds directly to the region's identified needs, including better teacher training, gender equity, stronger links between education and innovation, and greater student engagement. The project's approach - context-based STEM teaching; connection to sustainable development and major societal challenges; modular thematic days; co-creation of teaching materials with target audiences (students and teachers); digital, user-friendly resource creation; teacher empowerment; multi-stakeholder collaboration; immersion in real innovation ecosystems (research and industry); gender equality in real action; and capacity building for informed career decisions - offers a scalable and adaptable model. Its application in the Balkan context seeks not only to raise STEM interest and appreciation but also to promote regional peacebuilding, inspired by CERN's model of international scientific collaboration and initiatives such as SEEIIST [**Error! Bookmark not defined.**], which are p articularly relevant for Balkan post-war countries. The program's scale-up focusing the cross-border engagement and science diplomacy in Balkans has potential for tangible impact not only in terms of STEM education but also peacebuilding. The initiative can be adapted to support education reform, scientific literacy, and peace through science across the Balkan region and beyond, building on the success of pioneering STEM education models developed in Switzerland and further tested in Slovenia.

4. Conclusions

The transition toward future-oriented, inclusive, and sustainable science education in the Balkans depends on holistic reform and multi-level cooperation. Policies should emphasize teacher reskilling, gender balance, student participation, and stronger partnerships with industry and research institutions. Yet, the key lies in creating learning ecosystems that integrate scientific knowledge with ethical, social, and environmental awareness.

Initiatives such as Youth@STEM4SF provide a concrete and adaptable model for achieving this transformation. By embedding sustainability and innovation into STEM education, and by empowering both students and teachers to co-create solutions, such programmes can play a pivotal role in shaping a new generation of scientists, educators, and citizens equipped for the challenges and opportunities of the Fourth Industrial Revolution.

The conclusions presented in this paper should be understood as indicative rather than definitive, reflecting expert perceptions and pilot-based observations rather than a systematic comparative evaluation of education systems. Future work should aim to complement these qualitative insights with structured quantitative data on curricula, teaching practices, and learning outcomes across the Balkan region. In this context, initiatives such as Youth@STEM4SF can serve both as experimental platforms for innovation and as sources of empirical evidence to inform education policy and reform.

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