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STEM Teacher Education in the 21st Century:

Challenges and Opportunities

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**STEM Teacher Education
in the 21st Century:
Challenges and Opportunities**

Proceedings of the
5th Educating the Educators Conference

Maria Evagorou, Oliver Straser, Elena Schäfer, Katja Maaß (Editors)

Proceedings of the 5th conference Educating the Educators, hosted
jointly by the project ICSE Academy, ICSE, the ICSE Consortium
and the University of Nicosia.
8-9 May 2025 in Limassol, Cyprus

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Foreword

STEM education is currently shaped by rapid technological and societal change. Developments such as artificial intelligence, automation, mobile technologies, and social media affect everyday life, communication, work, and access to information. These developments create new opportunities for teaching and learning, but they also raise new challenges, including misinformation, increasing complexity, and growing demands on learners and educators (Chiu & Li, 2023).

At the same time, education systems in many countries face substantial pressure. International studies such as TIMSS and PISA have pointed to declining student performance in mathematics and science in several contexts (OECD, 2023; von Davier et al, 2024). In parallel, many teachers report increasing workload and more difficult working conditions (Nguyen & Kremer, 2022). As a result, STEM education is expected to address a growing range of demands under increasingly challenging circumstances.

These developments require more than isolated innovation. A central difficulty lies in the fact that the actors relevant to STEM education often work in separate contexts. Teachers, teacher educators, researchers, policymakers, and industry representatives contribute different forms of expertise, but they do not always work closely together. This limits exchange, mutual understanding, and the implementation of promising approaches across different levels of the education system.

The *Educating the Educators* (ETE) conference series was established to address this challenge. Since its launch in Essen in 2014, followed by conferences in Freiburg in 2016 and 2019 as well as Utrecht in 2023, the series has provided a platform for exchange between research, practice, policy, and other stakeholders in STEM education (Maaß et al, 2015, Doorman et al, 2024). Its aim has been to support dialogue on the implementation, scaling-up, and sustainability of innovation in STEM teaching and teacher professional development.

The ETE 2025 conference documented in this volume took place in Limassol, Cyprus in 2025 and was organised by the project ICSE Academy, ICSE, the ICSE Consortium and the University of Nicosia. It continued this work and focused on four thematic areas: (1) sustainability, (2) diversity, (3) digitalisation, and (4) interdisciplinarity. These themes reflect central questions currently shaping STEM education. (1) Sustainability points to the role of STEM education in helping learners understand and address environmental and societal challenges. (2) Diversity highlights the need for inclusive approaches that take different backgrounds, needs, and strengths into account. (3) Digitalisation raises questions about infrastructure, professional development, and the meaningful use of digital tools in teaching and learning (Zancajo et al, 2022). (4) Interdisciplinarity addresses the need to connect disciplinary perspectives in order to engage with complex problems that extend beyond individual subjects.

Across these themes, the conference was guided by an understanding of STEM education that goes beyond the acquisition of disciplinary knowledge alone. It also includes

the ability to question claims, evaluate evidence, and engage with complex issues in a reflective and informed way. In this sense, STEM education is linked not only to subject learning, but also to forms of reasoning and participation that are relevant in a broader societal context

In line with this perspective, the conference aimed to create space for exchange between different groups involved in STEM education like teacher educators, policymakers, teachers, and various other stakeholders involved to STEM education.

In addition to research presentations and workshops, formats such as round tables, policy seminars, and activities involving teachers were intended to support dialogue across professional and institutional boundaries.

The contributions collected in these proceedings reflect this range of perspectives. They include research-based, conceptual, and practice-oriented contributions and address current developments, challenges, and approaches in STEM education from different national and institutional contexts. Taken together, they document the main discussions of the conference and contribute to the ongoing exchange on the future of STEM education.

The Conference Chairs:

Maria Evagorou, Oliver Straser, Katja Maaß

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Welcome Message at the Educating the Educators 2025 Conference

Maria Evagorou
University of Nicosia, Cyprus

We live in a world transformed by science, technology, engineering, and mathematics. From the smartphones on which we rely daily, to medical innovations saving lives, STEM fields touch every aspect of modern life. STEM education is more crucial than ever – it doesn't just focus on teaching facts; it aims to cultivate critical thinking, problem-solving skills, and innovation in our students and prepare them to become responsible future citizens. In short, STEM education can equip learners with the abilities they need to navigate and improve an increasingly complex world. Our goal as educators is not only to prepare students to become future scientists or engineers, but also to empower all young people to apply their knowledge in practical, creative ways, and to understand the connection between school knowledge and everyday life. If we succeed, today's students will become tomorrow's innovators and informed citizens, ready to tackle global challenges ranging from the climate crisis and the ethical uses of AI to public health.

Yet, even as the importance of STEM grows, we are faced with questions such as: Are we reaching all students? Are we preparing them well enough? International assessments like PISA and TIMSS shine a light on how education systems are doing in STEM. The data are both illuminating and motivating. On the one hand, there are success stories – some countries consistently excel and improve. On the other hand, the overall picture reminds us that much work remains to be done. For example, PISA 2018 results showed that one in five 15-year-old students in the EU could not complete basic tasks in reading, mathematics, or science. This is not just a worrying statistic – it's a call to action, a reminder that STEM education must be made more effective and inclusive so that every child gains essential skills.

The findings from international studies highlight persistent challenges: *achievement gaps, gender disparities, and uneven progress*. All of this underscores a fundamental point: quality STEM education for all is not yet a reality, and it is our collective responsibility to change that. The purpose of this conference – and of the ICSE community and ICSE Academy Project – is to tackle these challenges head-on. The purpose of the ETE 2025 conference is to share ideas on how to boost student engagement, how to support struggling learners, how to make STEM classrooms more inclusive and exciting for every child. An additional goal of the ETE 2025 conference is to learn from each other's successes and failures on this journey.

Fortunately, supportive initiatives and policies are emerging at national and international levels to help us in this mission. For example, the European Union has stepped

forward with a strong vision and concrete actions to improve STEM education and teacher training. Some of these initiatives are highlighted below:

- Horizon Europe – the EU’s flagship research and innovation program – is investing in educational innovation, including STEM.
- Digital Education Action Plan (2021–2027) – the European Commission’s plan for the digital age.
- Initiatives like Erasmus+ Teacher Academies, of which ICSE Academy is part, are developing new models of mobility for teachers’ training.
- The recent JRC publication titled STEM and STEAM education, and disciplinary integration: a guide to informed policy action which paves the way to integrated STEM and STEAM education.

These initiatives – and many others – reinforce the purpose that brought us together for this ETE 2025 conference. They provide funding, frameworks, and political will. But policies and programs, as important as they are, only come to life through people. It is often said that *the quality of an education system cannot exceed the quality of its teachers*. To that I would add: the quality of teachers cannot exceed the quality of the training and support we provide them. Every time you equip a new STEM teacher with effective pedagogical skills, or inspire an experienced teacher to try a fresh approach in their classroom, you are impacting not just one educator but hundreds of students they will teach over the years. This is both a responsibility and an incredible opportunity for positive change.

Crucially, we must not work in isolation. The challenges of STEM education are complex and varied. No single school, university, or country has all the answers. That’s why collaboration – the very spirit of this conference – is so important. By sharing our diverse experiences and perspectives, we can collectively develop better solutions.

The ETE 2025 conference is supported by the ICSE Academy project which has worked to strengthen collaboration between educators, teachers and policy makers. What is the ICSE Academy? ICSE Academy is one of the Teacher Academies funded by the EU, from the first year of funding, and it comes to an end at the end of May 2025. It is a collaboration of 13 higher education institutions and 13 policy organizations, working with 65 schools in 13 countries – all united by the aim of innovating STEM teacher professional development. What makes this project special is not only its approach, but also the people. The ICSE Academy offered job shadowing activities trainers and teacher educators to learn from colleagues in other countries, workshop series for teachers, and summer schools hosted in different countries, where participants learned from one another’s practices. Every activity has been designed with a European lens – to provide “enriching European perspectives on STEM education” and to learn *about, from, and for* each other.

The aims of ICSE Academy align perfectly with the broader goals we discussed. The mission is to reduce the number of low-performing STEM learners by investing in a high-quality STEM teacher workforce and fostering European partnerships in teacher education. In essence, by improving how we prepare and develop teachers, we improve student outcomes – especially for those who struggle the most with STEM. The project recognizes that when we pool our expertise and learn from each other, we can raise the overall quality of STEM teaching across Europe. The ICSE Academy has created a vibrant community and the ETE 2025 conference itself is a testament to that community. The purpose of STEM education in the 21st century is nothing less than to empower the next generation to build a smarter, more sustainable, and more just world. Our role as teacher educators and leaders is to give them the best start possible.

The Hosts

ICSE Academy

The main host of the ETE 2025 Conference was the ICSE Academy Project. The ICSE Academy project is an ambitious Erasmus+ Teacher Academy project addressing the critical need for advancing STEM education across Europe by building a robust, high-quality STEM teacher workforce. Its primary objective is to reduce the proportion of underperforming STEM learners through equipping educators with innovative, effective teaching methods that meet the challenges of today's educational landscape. The emphasis of the teacher professional development activities of the ICSE Academy project have been on STEM pedagogical practices, digital transformation, sustainability, and inclusion in STEM education.

The ICSE Academy focused on fostering collaboration, mobility, and the integration of a European perspective into teaching practices, the project ensures a holistic approach to teacher education. It draws on a dynamic partnership of 13 countries, uniting higher education institutions, policy makers, and schools to develop and implement cutting-edge professional learning formats, such as peer-learning through job-shadowing, interdisciplinary European workshops, and collaborative summer schools. These formats are tailored to enhance teacher competence, promote knowledge exchange, and bridge gaps in STEM education, ultimately fostering a unified European STEM education ecosystem.

Details about ICSE Academy are available here: <https://icse.eu/icse-academy/>

The ICSE Academy (proSTEM) project (2022-25) is co-funded by the European Union under grant no. 101052670

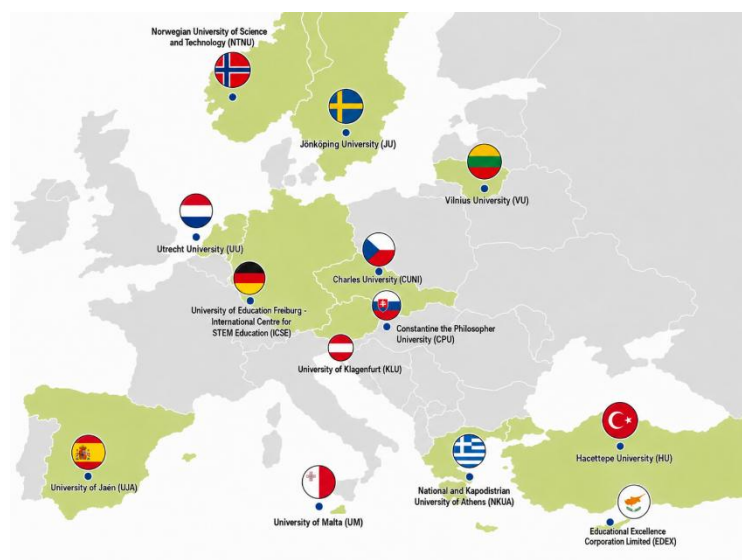


Figure 1 proSTEM Consortium (<https://icse.eu/icse-academy/about-us/>)

The International Centre for STEM Education Freiburg

The International Centre for STEM Education (ICSE) is located at the University of Education in Freiburg, Germany. It is dedicated to practice-oriented research and to the systemic transfer of research-based insights into educational practice. ICSE's overarching aim is to contribute to the improvement of STEM (Science, Technology, Engineering and Mathematics) education across Europe and beyond. At the heart of ICSE's work is the ambition to provide learners with meaningful insights into authentic features of STEM subjects and their relevance to real-life contexts, to raise achievement levels in STEM subjects and to make science literacy accessible to all students, no matter their gender, their cultural or socioeconomic background. Thereby, ICSE intends to strengthen the interest of young people in STEM-related careers and to contribute to a more inclusive and future-oriented STEM education landscape.

Our current work focus on several key areas in STEM education: these include inquiry-based learning, authentic connections to real life contexts and the world of work, interdisciplinary STEM tasks, digitalisation in STEM education, multicultural perspectives and citizenship education in STEM classes.

Our vision is that STEM teaching sparks enthusiasm for STEM subjects, supports the development of knowledge of and about STEM, enables learners to understand the relevance of STEM for our lives, our society and our future. STEM education should empower all young people to become responsible citizens who are able to engage critically and constructively with scientific, technological and societal developments.

In line with this vision, ICSE strives to be a central point of contact for all people involved in STEM education: from educational research to non-formal learning providers to policy and the world of work and innovation-driven industries. Our activities in these areas include, amongst others, the development, classroom-based evaluation and refinement of high-quality teaching materials and professional development resources, conducting professional development courses and student workshops and summer schools as well as the organization of international conferences and other educational activities. Furthermore, ICSE develops and coordinates numerous local, national and international projects.

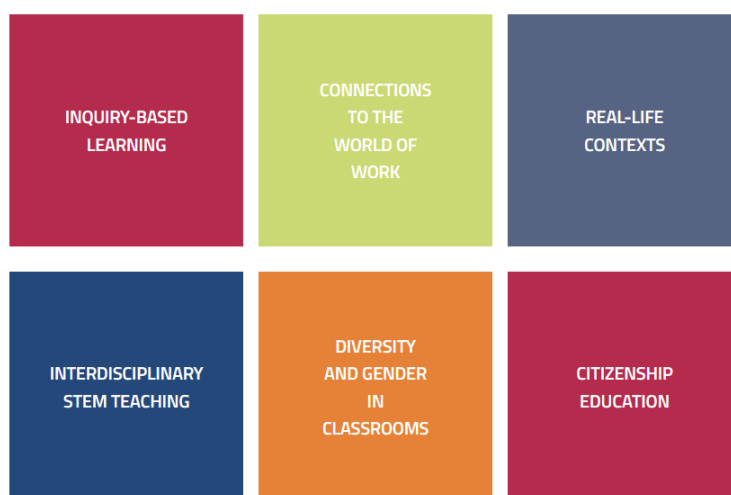


Figure 2 Foci of ICSE (<https://icse.eu/about-us/what-is-icse/>)

To reach these goals, three aspects are central to the work of ICSE:

- **Practice-related research:** ICSE focuses on practice-related research. Through the development of teaching materials and professional development formats, ICSE aims to transfer research-based insights into educational practice.
- **Working on the international and national level:** We are working, both on the international and national level, to promote productive exchange between different countries as well as between stakeholders from our local, regional and national levels.
- **Cooperation of key actors:** Only through a close cooperation of stakeholders from research, practice, policy and industry, we can successfully develop the future of STEM education.

ICSE is convinced that sustainable change in STEM education requires the active cooperation between all key actors involved in STEM education as listed above. For this reason, ICSE fosters cooperation on regional, national and European level. One example is the international conference series “Educating the Educators”, which brings together researchers, practitioners, teacher educators, policy makers and other stakeholders in STEM education. Since its launch, the conference has been held five (2014, 2016, 2019, 2023 and 2025) and has become an important forum for dialogue on innovation and professional development in STEM education. The next ETE conferences are planned in 2027 as well as 2028.

Beyond these activities ICSE continues to cooperate with a wide range of partners and stakeholders in various, - mainly European – STEM education projects. In these projects, ICSE develops research-based materials for classroom teaching, teacher education and professional development courses and implement related activities, including summer schools or open schooling projects in partner countries. Through this work, ICSE contributes to the advancement of high-quality, inclusive and practice-oriented STEM education across Europe.

For more information on ICSE please visit: <https://icse.eu/>

International Consortium for STEM Education

International collaboration is the key to continuous improvements in European STEM education. For this reason, ICSE together with its longstanding international partners initiated the foundation of an International Consortium for STEM Education in 2017.

As an association of 18 higher education institutions and research institutes the consortium unites vast expertise in STEM education. Its partners are internationally recognised for their research-based work and share a unique focus: The transfer of STEM education research insights into day-to-day teaching. Together, they aim transfer-oriented research and development in STEM education and to set standards for high-impact international collaboration among higher education institutions and research institutes. All consortium partners are embedded in broad national networks and thus, they connect with schools, educational policy, enterprises and industry, non-formal STEM education providers. In this way, the consortium operates along the entire science value chain – from research and design to implementation, transfer into practice and evaluation. The solutions developed within the consortium are transnational in scope, while remaining adaptable to the specific educational contexts of different European countries.

The consortium was founded to further develop existing cooperation and strengthen the international ICSE network through various forms of collaboration and exchange including:

- **Joint research and development projects:** The consortium supports collaborative projects that address current challenges in STEM education and develop research-based approaches for practice.
- **International conferences and events:** The *Educating the Educators* conference series is a joint activity of the ICSE Consortium. It brings together researchers, teacher educators, teachers, policy makers and other stakeholders in STEM education to exchange research findings, practice-oriented approaches and innovative formats for STEM teacher education.
- **Communication, dissemination and publication:** Through newsletters, publications and other communication formats, consortium partners share insights, materials and developments with wider professional and academic communities. They also jointly publish classroom materials and professional development materials in English and in the respective national languages, as well as policy briefs aimed at supporting dialogue between research, practice and educational policy.

– **International exchange:** The consortium promotes the exchange of staff, researchers, teacher educators and students in order to foster mutual learning across institutional and national contexts.

– **Professional learning activities:** Summer schools, workshops and other educational formats provide opportunities for professional development, networking and the joint advancement of STEM education. This also includes joint international workshop formats such as *1h4teachers*, which support exchange between teachers, teacher educators and researchers across national contexts.

Through these activities, the ICSE Consortium contributes to a stronger European STEM education community and supports the development of inclusive, research-informed and practice-oriented STEM education across Europe.

The 16 member institutions of the ICSE Consortium:

- Austria, University of Innsbruck
- Austria, University of Klagenfurt
- Bulgaria, Institute of Mathematics and Informatics at the Bulgarian Academy of Sciences
- Croatia, University of Zagreb
- Cyprus, University of Nicosia
- Czech Republic, Charles University
- Germany, International STEM Centre, University of Education Freiburg
- Germany, Leibniz Institute for Science and Mathematics Education Kiel
- Greece, National and Kapodistrian University of Athens
- Lithuania, Vilnius University
- Malta, University of Malta
- The Netherlands, Utrecht University
- Norway, Norwegian University of Science and Technology
- Portugal, University of Lisbon
- Slovak Republic, Constantine the Philosopher University in Nitra
- Spain, University of Jaén
- Sweden, Jönköping University
- Türkiye, Hacettepe University

InSSTER, Department of Education, University of Nicosia

The Innovative SSTS (Science, Society, Technology) Education Research Center (InSSTER) is a multidisciplinary research center consisting of researchers from different disciplines within the field of education. Faculty members and researchers from the Department of Education have joined forces in the fields of inclusive research education, with links to science, society and technology with an emphasis on innovative and inclusive practices, entrepreneurship through dialogue and argumentation, science education, technology education and school development. The Center was officially approved by the University Senate and Council in January 2023. The main objectives of InSSTER are to: conduct state-of-the-art research under the umbrella of innovative and inclusive education with links to science, society and technology; participate in competitive EU calls and receive external funding for projects; establish a national and international network with relevant, researchers, schools, and policy makers; engage with society on issues related to inclusive science and technology education, and offer continuous training on skills, methodologies and technologies to its members and beyond.

InSSTER promotes research in education focusing on innovative and inclusive practices in Science, Society, Technology education. This involves transforming schools to cater to all children, including marginalised groups, aiming to eliminate exclusion. It also emphasises cultivating skills for global problem-solving, ensuring inclusive education, and addressing gender equality in digital skills. InSSTER aligns with the Digital Education Action Plan for comprehensive and high-quality digital instruction and training (European Commission, 2020).

The University of Nicosia (UNIC) under which InSSTER functions, is the largest university in Cyprus, with over 11,000 students, from over 70 countries across the globe. UNIC is an independent, co-educational, equal opportunity institution of higher education, which offers a wide range of programmes to students from around the world. The University pursues excellence in education through research and high teaching standards, in a continually improving academic environment. Research at the University of Nicosia focuses on a variety of global and local issues, including health, complex networks, social organisation, education, ICT, engineering, and environmental sustainability. Our researchers examine contemporary challenges from a wide range of perspectives, including technological and scientific advances, and modern culture and thought. They apply their expertise, derived from addressing local, regional and national concerns, to key issues with global impact; and develop teams to bring disciplinary strengths together to approach such issues. Cutting edge research is carried out in the areas of Educational Technology, Virtual and Augmented Reality, and Artificial Intelligence and Machine Learning.

The Department of Education at UNIC employs 13 full-time faculty and offers degrees in Primary and Preprimary Education, Masters' degrees in Education (with 8 specializations), and PhD in Education. It has links with several pre-primary, primary schools and secondary schools with which it collaborates on several projects. The Department of Education currently has over 5500 students enrolled and around 28% of its student population are non-Cypriots, something which makes it a multicultural institution where diversity and pluralism are valued. UNIC hosted the ETE conference through the InSSTER (Innovative Science Society Technology and Education Research) Center of the Department of Education.

Conference overview

Aims and objectives

ETE 2025 is an international conference on professional development in STEM education that brings together teacher educators, policy makers, teachers and various other stakeholders related to STEM education. ETE 2025 focused on implementing and scaling up innovative teaching approaches in STEM education. The aim of the conference was to discuss different approaches with a rich variety of participants on four broad tracks. The conference aimed, on the one hand, to provide researchers with an opportunity to present their work and, on the other hand, to create a forum in which teachers, teacher educators and policy makers could contribute their perspectives on shaping a better future. The focus was on 21st-century challenges in STEM education. The four conference tracks of ETE 2025 are outlined below:

Track 1. Diversity in STEM Education

Diversity in STEM classrooms is a crucial cornerstone in the ongoing conversation about advancing STEM education. This theme delves into the multifaceted landscape of diversity within STEM disciplines, with a particular emphasis on gender inclusivity, gender-sensitive pedagogies, and intercultural approaches. In contemporary society, fostering diversity in STEM classrooms has transcended beyond a mere social imperative; it has become an essential catalyst for innovation, progress, and societal transformation. Recognising the vast array of perspectives, experiences, and identities within STEM fields not only enriches learning environments but also drives innovation by leveraging diverse insights and problem-solving approaches. This thematic area invited scholars, educators, researchers, and practitioners to engage in meaningful dialogue and exploration of strategies to create inclusive STEM classrooms. Participants had the opportunity to share best practices, innovative strategies, and evidence-based interventions aimed at promoting diversity, equity, and inclusion in STEM classrooms.

Track Leader: Michiel Doorman, Utrecht University, Netherlands

Track 2. STEM Education in the Digital Era

Digitalization is one of the most significant topics of the 21st century. The rapid pace of technological development often leaves individuals struggling to understand these new tools. This evolution presents both challenges and opportunities for the educational sector. On one hand, the incorporation of new technologies - along with their potential and risks - into curricula is essential, while on the other hand, these technologies provide unprecedented teaching and learning opportunities. For example, the "digital divide" - a term describing the gap between those with and without access to digital technologies - poses a significant challenge in integrating these technologies into education. 3D technologies, such as 3D printers and augmented reality, render abstract teaching content more tangible, while AI-based tools assist teachers in lesson preparation and practice, and serve as personalized learning tools for differentiated

education. Overall, digitalization demands a new understanding of both what and how we teach and learn. This track included workshops featuring hands-on activities and best practice examples, alongside in-depth analyses and effectiveness studies that can illustrate the modern developments in STEM education in the digital age.

Track Leader: Gultekin Cakmakci, Hacettepe University, Türkiye

Track 3. Interdisciplinarity in STEM Education

The global expansion of STEM Education has been accompanied by a broad discussion about its meaning. Although there is no consensus on its definition, STEM Education generally entails the interdisciplinary integration of concepts and skills from at least two of the four disciplines represented by the acronym. Interdisciplinarity in STEM Education has particular relevance in addressing innovative solutions to authentic problems, where each STEM discipline plays a particular role in responding to these problems. Furthermore, involving students in exploring these authentic problems fosters the development of their STEM skills, including critical thinking, creative problem-solving, communication, and cooperation. Despite the potential benefits of interdisciplinary STEM Education for students, experiences involving STEM integration in the classroom remain relatively scarce. This thematic area invited scholars, educators, researchers, and practitioners to share best practices, interdisciplinary curriculum approaches, and evidence-based interventions aimed at promoting interdisciplinarity in STEM education.

Track Leader: Martin Bilek, Charles University Prague, Czech Republic

Track 4. Sustainability and STEM Education

Preparing the next generation for the future is of great importance. Issues and topics related to sustainability still often seem to be structurally interrupted in primary and secondary education or take an unclear or even contradictory approach in science, geography, citizenship and economics lessons. How do we teach about sustainability so that our students don't just see problems but develop a hopeful perspective? A perspective that shows that choices and actions matter and that the future is not a fait accompli. The need for action also concerns our STEM education community to make use of the transformational potential of teaching and learning. We need to share good practices, research results and innovative classroom materials that allow for implementing approaches that support the implementation and scaling up of education for sustainability. These actions are broad in scope and attend not only to the practices of teachers, teacher educators and researchers but also involve other important stakeholders, including school principals, policymakers and the students themselves. Moreover, these actions require and appreciate the capillarity of educational institutions and their communities and require collaboration and commitments that ensure educational opportunities and joint responsibilities.

Track Leader: Marta Romero Ariza, University of Jaen, Spain

Plenary Talks

The conference was opened by Jonathan Osborne from Stanford University with a plenary talk on scientific literacy in the 21st century. The talk emphasised the importance of developing students' capabilities to evaluate scientific information, which represents a central dimension of scientific literacy and a key competence for participation in contemporary society. It was pointed out that this competency was directly aligned with the 2025 PISA framework, which includes the ability to "research, evaluate and use scientific information for decision making and action." In the context of the current Age of Misinformation, the speaker pointed out that most existing science standards - developed over a decade ago - were not designed to address the widespread nature of misinformation. Although scientific literacy was a feature of these standards, they lacked the tools needed to help students critically assess information. The talk argued for a crucial distinction between evaluating the *source* of scientific information and evaluating its *content*. Since only expert scientists are typically equipped to assess content, it was proposed that science education should instead place more emphasis on teaching students how to evaluate sources. In the presentation, the foundational knowledge and competencies required for this purpose were explored, and potential changes to science standards were discussed. The ideas presented were closely connected to the competencies assessed in PISA 2025 and closely aligned with the goals of the ICSE Academy project in preparing educators for STEM education.



Figure 1. Jonathan Osborne during the first plenary talk

The second plenary talk was given by Anastasios Hovardas from the University of Cyprus and focused on the use of learning products to align pedagogical design, implementation and assessment in STEM and STEAM Education. Several persistent challenges in teacher training and professional development were addressed in this talk, especially the limitations of existing practices and solutions. These included: (1) the shift from a focus on content to skills, which raises the importance of engaging with content critically for both teachers and students; (2) the need for integrated STE(A)M

learning, requiring the inclusion of multiple STEM disciplines alongside arts, humanities, and social sciences; and (3) the rise of open-ended learning environments marked by uncertainty and unpredictability. It was argued that these challenges could not be



Figure 2. *Anastasios Hovardas during the second plenary talk*

met through traditional, linear pedagogical approaches, externally imposed assessment tools, or centralized leadership structures. The session examined how learning products - tangible outputs created by students during learning activities - can serve as a focal point for aligning pedagogical design, implementation, and assessment in STE(A)M education. Through selected examples, the speaker showcased the potential of pedagogical design in Inquiry Learning Spaces and demonstrated how participatory design processes could be structured with input from stakeholders in open schooling

projects. A detailed coding process was presented for evaluating the quality of learning products, along with strategies for using these insights in peer and formative assessment. The talk concluded with a discussion of the implications for open-ended learning contexts such as educational robotics and Makerspaces, and for the development of a European STE(A)M Roadmap and Competence Framework, aligned with initiatives like DigCompEdu, GreenComp, and EntreComp.



Figure 3. *Hilda Borko during the final plenary talk*

The final plenary talk took place on the last day of the conference and was given by Hilda Borko from Stanford University and focused on preparing and supporting professional development leaders. The increasing demand in recent years for professional development (PD) opportunities for teachers was addressed, along with the need for scalable, sustainable programs led by a broad base of well-prepared PD facilitators. To respond to these challenges, the speaker presented the *Learning to Facilitate Framework* (LTFF), a model developed by researchers from Germany, Israel, and the United States to support the preparation of PD facilitators. The LTFF outlined four core pedagogies: selecting a central task of facilitating PD, representing the practices within that task, approximating those

practices, and unpacking both the representations and approximations. To illustrate the framework in practice, the speaker analysed a facilitator preparation session from her research on the Problem-Solving Cycle model, which centres on leading video-based discussions. The talk concluded by exploring how both the Problem-Solving Cy-

cle and the LTFF could be used to design and study facilitator PD, with particular attention to strategies for promoting diversity and equity in mathematics classrooms.

The descriptions of all plenary talks, as well as short interviews with the speakers conducted after their talks and focusing on their reflections on interactions with the participants are available here: https://educating-the-educators.icse.eu/plenary_talks/

Conference Connection to the ICSE Academy Project

The ETE 2025 Conference marked the completion of a three-year European collaboration aimed at transforming professional development for STEM educators. The event showcased the project's contributions to policy, practice, and research in STEM education through interactive formats and inclusive participation. The plenary talks, round table discussions, workshops, and poster sessions demonstrated the project's alignment with European educational priorities, especially in promoting teacher mobility, fostering cross-disciplinary collaboration, and addressing 21st-century challenges such as misinformation, sustainability, and digitalization. Through its active engagement with stakeholders and its integration into the broader ETE 2025 community, the conference not only celebrated the achievements of the ICSE Academy but also laid the groundwork for continued European collaboration in teacher education.

The outcomes of the conference, including policy recommendations, training materials, and best practices, will contribute to sustaining the impact of the ICSE Academy and to advancing innovative and inclusive STEM education across Europe and are available through the project's website here: <https://icse.eu/icse-academy/>

The ICSE Academy Policy Round Table

The third and final ICSE Academy Policy Round Table took place on the last day of the conference, on May 9th and focused on teacher mobility in STEM education. The session included a panel discussion, a world cafe, a presentation of mobilities from different EU funded projects and a final discussion and summary. The topic of the round table was Teacher Mobility in STEM Education and was organised by the University of Nicosia (UNIC) which led the respective work package within the ICSE Academy project. This in-person round table built on two previous online round tables and brought together key stakeholders from education, government, academia, and industry. The aim was to explore the current landscape of STEM teacher mobility across Europe, identify challenges and opportunities, and propose concrete policy recommendations and practical strategies to enhance mobility and professional growth for STEM educators.

Maria Evagorou and Marta Romero-Ariza, both partners from the ICSE Academy project, opened the round table, with an introduction on the actions that took place during the ICSE Academy project that are linked to teacher mobility, and a brief presentation of the outcomes of ICSE Academy related to STEM teacher mobility. A panel discussion followed, with contributions from Agueda Gras-Velazquez, from the European Schoolnet, Verena Bodenbender, International Office of the University of Education Freiburg, Maria Podlasek-Ziegler, from DG EAC – European Commission, Brussels and Gregory Makrides, STEAME Teacher Academy Coordinator/University of National Education Commission, Krakow, Poland. The panel addressed questions related to the current state of STEM teacher mobility, including how existing policies support or hinder mobility, and how barriers such as certification, funding, and institutional structures impact mobility efforts.

A World Café session followed, moderated by partners of the ICSE Academy which enabled participants to explore these themes in greater depth through small-group discussions. The groups discussed key questions such as: How does mobility affect STEM education outcomes? What are the implications for teacher retention and professional development? What policy and institutional measures could support teacher mobility? *and* How can technology and digital platforms promote cross-border collaboration among teachers? Summaries of these discussions were shared in plenary, and posters were created to capture participants' insights and are also reflected in the paper by Anna Blattmann included in this volume.

In the next part of the Policy Round Table, Michiel Doorman (ICSE Academy), Gregory Makrides (STEAME Academy), Natalia Spyropoulou (SPICE Academy), and Mirjam Holtkemper (NBS4S) shared best practices from their respective projects, highlighting successful models of teacher mobility and their impact. The event closed with reflections by the organisers. Overall, the round table, which featured 40 participants in addition

to the presenters, fostered rich dialogue, collaborative problem-solving, and actionable policy recommendations for advancing STEM teacher mobility in Europe.



Figure 1. *The panellists from the policy round table and part of the world cafe*

The Teachers' Day

The Teachers' Day took place on May 8th 2025, during the first day of the conference. It was specially designed for teachers but was also open to teacher educators, researchers and policy makers. The Teachers' Day featured three sessions which provided a combination of panel discussions and a workshop. The first session focused on opening up schools to the real world and featured a panel with teachers, researchers and students who talked about the benefits of opening up the school from their perspectives and shared their experiences and challenges. A group of students from a secondary school in Limassol presented a project they completed during the current academic year, and teachers commented on their experiences. The second session of the Teachers' Day was an interactive workshop presented by Stephanos Cherouvis from Eccsite (European Network of Science Centres and Museums). During the workshop participants explored six evidence-informed criteria for high-quality STEAM practices, developed through the EU-funded Road-STEAMer project and engaged in a gallery walk, reflected on their own practices, and took part in a hands-on activity distinguishing sustainability from exploitation. In the final session of the Teachers Day was a panel discussion on teaching in the age of AI with a panel including researchers and teacher educators presenting ideas and challenges from implementing AI in their teaching, and closing with a keynote input by Scientix on a European perspective on STEM education and AI.

The ICSE Academy Policy Round Table as a Platform for European Dialogue on STEM Teacher Mobility: Bridging Policy, Practice, and Research

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Abstract

This paper analyses the ICSE Academy's third Policy Round Table (09 May 2025, Limassol, Cyprus) as a dialogic platform connecting policy, practice, and research communities across Europe. Moving beyond conventional dissemination formats, the round table served as a collaborative space for policy drivers, teacher educators, and practitioners to co-construct visions for sustainable STEM teacher mobility. Through a multi-level participatory process, the event demonstrated how European Teacher Academies can act as *interfaces* - bridging institutional silos, promoting mutual understanding, and shaping evidence-informed policy recommendations.

From Dissemination to Dialogue

The ICSE Academy (2022–2025) was founded on the principle that innovation in STEM teacher education depends on *systemic collaboration* among actors who traditionally operate in separate spheres, policy, higher education, and school practice. Within this framework, the third Policy Round Table did not merely *present* project outcomes but was deliberately designed to create interactional spaces where evidence, experience, and policy reasoning could meet. This event sought to *redefine the relationship* between policy makers and practitioners, from a top-down model of policy translation to a reciprocal exchange, where teachers' and teacher educators' lived experiences inform future European and national strategies for mobility and professional development.

A European Interface for Policy Learning

The Round Table gathered more than forty representatives from policy, universities, European networks, and schools. Participants were not treated as discrete categories but as members of an evolving ecosystem of teacher education. Policy drivers contributed strategic perspectives on system-level enablers and constraints, while teacher educators and practitioners offered grounded reflections from classroom and institutional realities. The event's structure, combining keynote input, expert panel, and a World Café, was conceived to stimulate horizontal learning among participants. This participatory architecture transformed the round table into a *policy laboratory*, where

ideas were collectively generated, visualised, and consolidated into cross-sector recommendations.

Connecting Scales of Influence

A distinctive feature of the ICSE Academy's policy approach is the integration of local, national, and European scales of action. Each policy discussion built on empirical insights from the Academy's professional learning formats (Job Shadowing, Workshop Series, Summer Schools) implemented in thirteen partner countries. The event thus created *vertical coherence*: evidence from teachers' mobility experiences and quantitative analyses (WP5) informed the conversations among decision-makers. This dialogic structure positioned teacher mobility not as an isolated opportunity, but as a lever for system-wide change, linking professional development, institutional recognition, and policy frameworks. The round table thereby advanced the project's third mission: *to inform policy on effective, accessible, and transferable STEM ITE and CPD formats*.

Towards a Culture of Shared Responsibility

One of the main conceptual outcomes of the round table was the recognition that sustainable European mobility requires shared responsibility across institutional levels. Participants identified four interdependent conditions for fostering such responsibility:

1. **Institutional Anchoring** – Embedding mobility and European collaboration in teacher education curricula and accreditation systems.
2. **Mutual Recognition** – Developing frameworks for acknowledging professional learning experiences across borders.
3. **Hybrid Flexibility** – Integrating digital and physical mobility formats to ensure inclusion and accessibility.
4. **Collective Reflexivity** – Maintaining iterative spaces for reflection among policy makers, teacher educators, and teachers.

These principles mirror the EU's call for *co-creation* in education policy and represent a concrete manifestation of how Teacher Academies can operationalise this vision.

Strengthening the European Policy Network

Beyond its immediate discussions, the round table contributed to the emergence of a European network of policy learning among Teacher Academies. By connecting ICSE Academy's national policy committees with other Erasmus+ Teacher Academies and the European Commission's *Community of Practice for Teacher Academies*, the event functioned as a nodal point in a wider infrastructure of collaboration. This illustrates how *Teacher Academies* can evolve from project consortia into long-term knowledge alliances, ensuring that the results of temporary projects are absorbed into lasting European processes of educational transformation.

Conclusion

The third ICSE Academy's Policy Round Table exemplified a shift in European education cooperation, from coordination to *co-construction*. By uniting policy drivers, researchers, teacher educators, and practitioners in a shared deliberative process, it demonstrated how multi-actor dialogue can translate evidence and experience into actionable policy frameworks. In doing so, it not only addressed the project's immediate objectives but also contributed to the sustainability of a European culture of collaboration in STEM teacher education.

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Papers

Developing a questionnaire to analyze the impact of 3D printing on students' self-efficacy expectations

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Keywords: 3D-printing, self-efficacy, teaching, gender, STEM

Abstract

This doctoral project examines the extent to which the practical use of 3D printing in mathematics lessons influences the mathematical self-efficacy expectations (SEE) of secondary school students and how this relates to gender-sensitive issues. To this end, an instrument for measuring students' mathematical SEE was first developed and piloted, which combines various validated scales (Jerusalem et al., 2009; Schwarzer & Jerusalem, 1999) with newly developed scales from the field of 3D printing in a modular fashion. This was followed by a main study in a pre-post control group design with three experimental arms (CAD + printing; CAD + printing + optimization + reprinting; control group without 3D printing) and a sample of approximately 300 students. SEE, task value, and spatial visualization were quantitatively assessed using pre- and post-questionnaires; this was supplemented by qualitative student group interviews for communicative validation.

The interview guide used for this purpose combines items and scale components from validated questionnaires, adapted and contextualized, and supplements them with items specific to 3D printing. In line with method triangulation, additional teacher interviews were conducted in June 2025 as a follow-up. The analysis includes paired t-tests, ANOVA, multilevel analyses, and qualitative content analysis. Participation in a workshop is expected to increase SEE, as 3D printing promotes geometric understanding through its haptics and the possibility of changing perspectives (Dilling, 2019; Dilling et al., 2021; Fahrländer, 2023; Fahrländer & Straser, 2021; Hykkelbjerg Wulff, 2025; Meier et al., 2022; Thyssen & Meier, 2023). It is of particular interest to investigate whether girls' SEE increases to a greater extent than boys' and whether 3D printing workshops could therefore offer a way to reduce the SEE gap between the sexes. The results should contribute to the theory-based promotion of SEE in STEM subjects and provide practical recommendations for teachers.

Introduction: 3D Printing in Mathematics Education

The decision to pursue a STEM career depends not only on an interest in mathematics, but also on general SEE (Jann & Hupka-Brunner, 2020). International comparative studies like PISA repeatedly show that boys have higher SEE regarding mathematical and simple application tasks than girls (Diedrich et al., 2023). 3D printing can be utilized as an innovative teaching/learning tool to potentially counteract this (Fahrländer, 2023). The practical and tactile handling of printed objects can strengthen spatial thinking, and technical functionalities are more easily understood (high visual clarity; spatial experience) (Novak et al., 2021). 3D printing (especially in STEM subjects) can be an innovative way to develop important skills such as systemic thinking and problem-solving strategies and can offer decisive added value thanks to its vividness.

Based on the current state of research and taking into account previous experience in the project, an intervention was developed to influence the mathematical SEE of students. It is to be expected that 3D printing will increase students' SEE, as 3D printing promotes geometric understanding through its tactile nature and the possibility of changing perspectives (Fahrländer, 2023; Fahrländer & Straser, 2021).

Theoretical framework

Functionality of an FDM printer

The fused deposition modelling process (FDM) is used almost exclusively in the education sector. Here, plastics (filaments) on spools are usually loaded into the extruder of

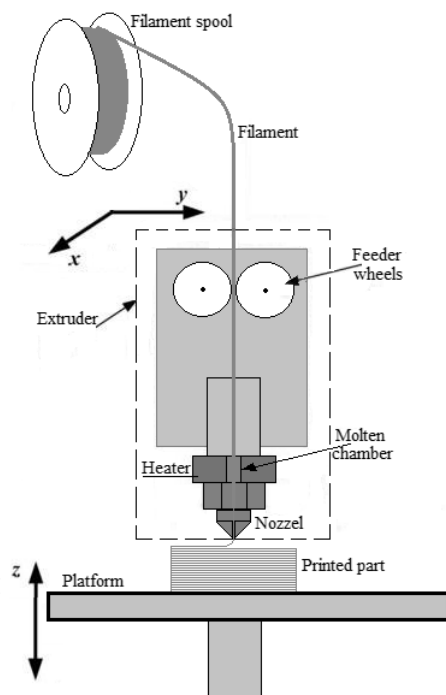


Figure 1. Schematic diagram of the FDM printer (Abbas et al., 2022)

the printer, heated in its heating block and thus liquefied and pressed out through a nozzle. The material is then applied layer by layer ("layer building principle") on the x-y level of the print bed, with the nozzle moving upwards on the z-axis at a predetermined distance after each layer and then starting to apply the next layer (Dilling et al., 2021). PLA (polylactide) is often used as a filament. These are synthetic polymers that are almost completely biodegradable when recycled according to type and are also non-toxic and relatively affordable (Fahrländer & Straser, 2022b).

Learning theory basis for haptic 3D model work

Haptic experiences and active engagement with material objects are described in learning research as conducive to deeper understanding and sustainable concept formation (Barsalou, 2008; Wilson, 2002). From a learning theory

perspective, three interrelated mechanisms of action can be distinguished for the present context: (1) multimodal coding and embodied learning, understood in the sense of a close link between cognitive processes and physical actions and sensory experiences (Wilson, 2002), as well as the assumption that abstract thinking is “grounded” in sensory-motor experiences (Barsalou, 2008), (2) mastery experiences (Bandura, 1997) and associated effects on self-efficacy, and (3) improved opportunities for error diagnosis and processing (Carbonneau et al., 2013; Hattie & Timperley, 2007).

Gender-sensitive promotion of mathematical self-efficacy through 3D printing projects

Gender-specific differences in mathematical SEE are well documented in educational research (Gildehaus, 2024; Laursen et al., 2014). In particular, differences in participation and learning strategies are gender-specific. Project-based, co-creative, and action-oriented learning formats, such as those enabled by the use of 3D printing, offer several advantages in this context:

On the one hand, 3D printing enables low-threshold, self-directed access to complex mathematical content. Even if they already have negative self-attributions and stereotypical beliefs, students can independently design and iterate models based on mathematical modeling, creating controlled experiences of success that in turn specifically strengthen SEE. In addition, 3D printing projects can promote active participation and problem-solving strategies, as students are involved in all phases of the project, from planning and construction to error diagnosis. The combination of visual, haptic, and project-based elements offers alternative learning paths that can be particularly beneficial for female students with less affinity for traditional, abstract-symbolic learning settings (Güçler et al., 2012). This directly addresses the differences in the use of learning strategies between the sexes documented in research (Liebendörfer et al., 2020). Furthermore, the cooperative nature of the projects can open up learning opportunities that include social interaction and peer feedback. Last but not least, the targeted presentation of the work results and the active role of the female students in the project can increase the visibility and representation of female learners, which weakens stereotypical attributions of talent and “non-femininity” in mathematics learning (Denn, 2021; Foyn et al., 2018). 3D printing projects can therefore offer an opportunity to promote SEE among all students. However, learners who initially have lower SEE - often girls - benefit more from these mastery experiences. In this way, the intervention can not only increase overall SEE, but also specifically contribute to reducing existing gender differences in mathematical SEE.

Methods

Research Questions

- RQ1** What influence does the use of 3D design and 3D printing in mathematics education have on self-efficacy expectation in this subject?
- RQ2** Is there a difference in self-efficacy expectations between genders?
- RQ3** Are there differences in the degree of change in self-efficacy expectations due to 3D printing between genders?
- RQ4** Do other personal factors also influence self-efficacy expectation or task value?

Research design

This doctoral project aims to investigate the effectiveness of using 3D printing in mathematics education, focusing on students' SEE. For this purpose, an instrument to measure SEE was developed in spring 2024 and piloted with $n = 61$ participants. The core of the questionnaire consists of two scales on the constructs of SEE and task value, with items primarily derived from the instruments of Hay et al. (2022) and Yurt (2022), which in turn are based on the tested scales of Schwarzer und Jerusalem (1999). The questionnaire was optimized in several iteration cycles. The main study was conducted in winter 2024; the quantitatively collected data was subjected to validation in the form of group interviews with the students. A follow-up in terms of method triangulation in form of teacher interviews was realized in June 2025.

03/2024

- Item Validation by Experts

04-07/2024

- Questionnaire Piloting & Revision
 $n = 61$

11-12/2024

- Quantitative Data Collection
(Students Questionnaire), $n = 300$

01/2025

- Validation (Group Interviews with Students)

06/2025

- Qualitative Data Collection (Teacher Interviews)

Figure 2. *Research design: Data collection*

The questionnaire contains items from the following categories:

- Personal background
- Prior knowledge
- Self-efficacy expectations
- Task value
- 3D printing comprehension questions
- Product evaluation
- Process evaluation

Intervention

In this study, a four-hour 3D printing workshop was conducted as an intervention to influence mathematical SEE. The workshop was divided into a brief theoretical introduction to CAD and 3D printing (How a FDM printer works, slicing process, operation of the CAD program), a practical phase (Design of a given 3D model and customization), observation of the print (accompanied by reflection questions), optimization of the own model, renewed printing.

First results and discussion (Paired *t*-Test)

These values indicate a significant improvement in SEE after the intervention. The extremely low *p*-value suggests that the likelihood of this result occurring by chance is very small. Cohen's *d* of 0.41 indicates a medium effect size.

Task value also shows a significant improvement, although the effect size is smaller (Cohen's *d* = 0.24, indicating a small to medium effect).

Table 1.

*Results of the paired *t*-test*

Construct	Cronbach's Alpha	<i>t</i> -value	<i>p</i> -value	Cohen's <i>d</i>
Self-Efficacy Expectations	Pre .91	4.63	<i>p</i> <.001	0.41
	Post .93			
Task value	Pre .83	2.69	<i>p</i> <.01	0.24
	Post .89			

In the further course of this doctoral project, the qualitative data already collected from the various interviews will be evaluated and analyzed.

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Rooting Change: Nature-Based Solutions, Citizen Science, and School-Based Youth Activism as Catalysts for Climate Education. Analyses within the framework of the NBS4S project.

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Abstract

In the face of escalating climate challenges, education systems are increasingly called upon to foster environmental responsibility, scientific literacy, and civic engagement. This article examines how the integration of Nature-Based Solutions (NBS), citizen science, and school-based youth activism can function as an effective pedagogical approach to climate education. Drawing on eight diverse case studies, the article explores how NBS initiatives were implemented in schools across Europe and how their impact was perceived by those directly involved in their realization. Based on 14 qualitative interviews (1-2 participants per case), the authors describe both the processes of implementation and, in part, the assessments of educational outcomes. In addition to presenting these insights, the authors have distilled practical recommendations for educators based on the experiences shared during the interviews. While the projects differ in scale, context, and degree of curricular integration, they collectively illustrate the transformative potential of experiential and participatory learning. Our findings suggest that, when strategically supported, NBS initiatives in schools can promote ecological stewardship and prepare students for active sustainability roles. This study contributes to the discourse on Education for Sustainable Development (ESD) by providing examples and actionable strategies for incorporating sustainability into school practices through nature-based solutions.

Introduction

In light of the escalating climate crisis, the role of education in fostering ecological responsibility has never been more crucial (Bryan, 2022). Schools are key arenas for instilling environmental awareness and promoting sustainable behaviour. Therefore, it

is important to determine how teachers can raise environmentally responsible students in schools (del Carmen Pegalajar-Palomino et al., 2021). As discussed in this article, Nature-Based Solutions (NBS), citizen science and school-based youth activism can offer powerful and complementary approaches to climate education. This article examines why these three concepts should be implemented in schools to help generate a generation of environmentally active students. It examines the implementation of eight school-based nature-based solutions projects, presenting practical insights from interviews with key stakeholders involved in these projects.

Theoretical Framework/Literature Review

Nature-Based Solutions (NBS). According to the European Commission (n.d.), NBS are: “Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient and systemic interventions”. By making use of natural ecosystems and the benefits they offer, Nature-based Solutions help address key global issues such as climate change, securing food supplies, and managing natural hazards (Cohen-Shacham et al., 2016, p.2). In an educational context, NBS could provide an opportunity to combine environmental stewardship with practical learning. This can foster critical thinking, deepen understanding of complex environmental issues, and may promote students’ environmental citizenship and activist competences (Linhares & Reis, 2023). Access to nature during childhood is strongly linked to a wide range of developmental benefits (see Chawla, 2015, p. 435). Research shows accordingly that natural environments are connected with healthier physical development, including improved motor coordination, more frequent moderate-to-vigorous physical activity, and healthier weight. Cognitive and emotional benefits include enhanced concentration, reduced stress and psychological distress, and increased creativity. Access to nature is also linked to imaginative play, cooperative social interactions, and overall well-being. Additionally, a recent study of UK school playgrounds (Redondo Bermúdez et al., 2023) has shown that green infrastructure in school settings can improve air quality with significant reductions in air pollution levels. Furthermore, a meta-analysis by Ferrario et al. (2024) demonstrates that Nature-based Solutions generally have a positive impact, notably contributing to temperature regulation and flood protection across various implementations. In summary, green spaces can serve as dynamic learning environments, providing students with the opportunity to engage in hands-on activities such as data collection and biodiversity monitoring. These activities should encourage interdisciplinary learning and foster a sense of environmental responsibility.

Citizen Science. In this regard, Bonney et al. (2009) point out that citizen science has emerged as a powerful approach to engaging the public in large-scale data collection efforts across diverse habitats and over extended periods of time. If carried out

correctly (see Shirk et al., 2012), such initiatives can make a significant contribution to our scientific understanding, particularly with regard to tracking species distributions and occurrences worldwide (Bonney et al., 2009). In addition to generating valuable scientific data, citizen science projects can aim to increase participants' knowledge of biodiversity and provide insight into the scientific process. Empirical evidence suggests that (school-based) citizen science not only improves understanding of environmental science and inquiry practices but also supports the development of environmental science agency among young people (Ballard et al., 2017). This includes fostering identification with scientific practices and the belief that they can influence ecological systems. Ballard et al. (2017) found that the central processes that support this development are rigorous data collection, the communication of findings to external audiences, and the exploration of complex socio-ecological systems.

Youth Activism. Young people are increasingly voicing their opposition to social, economic, and environmental policies and practices (O'Brien et al., 2018), a phenomenon often referred to as youth activism. Rooted in the principles of Education for Sustainable Development (UNESCO, 2017), it positions learners as active agents of transformation. Not only can involvement in youth activism drive potential social and environmental change, but studies also show that it offers young people multiple personal benefits (Montague & Eiroa-Orosa, 2018). Many participants seem to develop a strong sense of belonging, efficacy, stimulation, and integrity through project-based activism (Harré, 2007; Reis, 2025). As outlined by Cloughton (2021, p. 5), based on existing literature and current research, there is a suggested link between knowledge and attitudes, as well as between attitudes and activism, and therefore these findings have led some scholars to argue that educational systems may be shaping students' attitudes in ways that foster greater interest in and engagement with climate activism.

Synergies and Educational Potential. The integration of NBS, citizen science, and youth activism presents a particularly powerful pedagogical triad. Each element can reinforce the others: NBS provide the context and content for environmental engagement, citizen science introduces inquiry and evidence-based learning, and activism ensures student ownership and relevance. Jensen and Schnack (1997), for example, emphasise the relevance of action competence as a core educational goal, highlighting the importance of empowering learners to engage critically and take meaningful action. Therefore, the authors of this article believe that combining the three aforementioned concepts offers the opportunity to create participatory, place-based and impactful learning environments, enabling students to understand climate change and develop the skills and attitudes needed to take informed and responsible action.

Methods

Eight NBS projects were selected as case studies to deliberately reflect a diverse range of educational and contextual factors. The selected projects also vary in the types of Nature-Based Solutions implemented, from green roofs and food forests to

wetland restoration and composting systems. This diversity provides a well-rounded perspective on how NBS can be adapted and applied across different educational contexts and institutional structures. The Case Studies are based on a qualitative investigation of eight exemplary Nature-Based Solutions projects. Semi-structured interviews were conducted with one to two individuals responsible for its implementation, resulting in a total of 14 interviews. Due to high demand for interviews with those involved in these projects, it was not possible to conduct any more interviews. Consequently, a limited amount of data was available for scientific analysis. However, even though the data is insufficient for an in-depth scientific analysis, it does provide an interesting and profound insight into the implementation of various NBS projects in schools. Interviewees included mainly teachers but also included other representatives who were involved in the implementation of the project. These participants shared their experiences, highlighting both effective strategies and encountered challenges. As the projects were conducted across different countries and languages, interviews were analysed by different members of the research team. Guided by a overarching semi-structured interview framework, each project was systematically examined for relevant information. To ensure consistency and comparability, the individual findings were centrally harmonized. The following section strongly summarises the core elements of the projects based on the conducted interviews and online project presentations. At times, content is framed within a broader analytical perspective, in order to align with the analytical focus of the article. The complete case studies can be requested from the authors.

Results

Case Studies. This section presents eight examples illustrating exemplary NBS projects.

Green Roof and School Garden – Braunschweig, Germany. To address urban children’s limited access to nature and science education, the school partnered with the Technical University of Braunschweig to create green spaces, starting with a flower bed and expanding to rooftop and courtyard gardens. A rotating working group involved all pupils, while herbs and vegetables were cultivated for school use and gardening activities were linked to science, math, and arts curricula. A dedicated staff member supported cross-disciplinary integration. Democratic participation was emphasized, with pupils choosing responsibilities and parents, experts, and local groups strongly involved.

Promoting Biodiversity through School Gardening – Braunschweig, Germany. At a special needs school, unused outdoor areas were transformed into thematic gardens. Accessible features such as raised beds and QR-coded signs enabled inclusive learning. Project days engaged all classes within a broader Education for Sustainable Development (ESD) strategy. Students monitored pollinators and used produce in the cafeteria, reinforcing local food cycles. Partnerships with grammar schools and biodiversity experts expanded learning formats, while an ESD department institutionalized sustainability at the school.

OASIS Schoolyards – Paris, France. This municipal initiative aims to convert 700 schoolyards into climate-resilient spaces by 2050. Students co-designed solutions through workshops, models, and brainstorming, fostering a feeling of ownership and creativity. The project promoted outdoor pedagogy and experiential learning. Partner universities monitored impact via fieldwork, interviews, and

sensor data. Redesigned yards reduced heat stress, improved biodiversity, and strengthened bonds between schools and their environment.

ReDuna Coastal Restoration – Almada, Portugal. ReDuna restored 7 km of vulnerable dunes through collaboration among students, teachers, NGOs, and municipal staff. Activities included sand-retention palisades, planting native species, and building walkways from recycled materials. Education was grounded in project- and inquiry-based learning, with pupils collecting and planting seeds. Art projects using marine litter raised ecological awareness. Community engagement included volunteering days and signage. Informal observations suggest increased awareness and stewardship.

Food Forest – Thessaloniki, Greece. This project transformed a degraded hillside into an educational landscape with 400 students, local schools, and the municipality. Preparatory workshops combined co-design with team-building. Students led awareness campaigns and co-hosted a community planting day with food, music, and activities. Afterward, pupils, municipal staff and the environmental organisation involved in the project maintained the site, supported by a “caretakers” group. The initiative fostered skills such as teamwork, decision-making, and active citizenship, while participatory learning deepened understanding of climate change and urban NBS.

Green Schools 2.0 – Multiple Countries. An Erasmus+ collaboration across six countries, this project integrated NBS into curricula on water conservation, energy saving, recycling, waste reduction and pollution. Activities included vertical gardens, workshops e.g. on microplastics and composting, and mobility programs to farms and treatment facilities. Teachers used tools like Gantt charts, while students created media to promote sustainable behavior. The project strengthened critical thinking, teamwork, and awareness of climate change.

Composting with STEAM – Cyprus. At a forest school, children composted food and leaf waste from meals. The process began with problem identification and material selection, followed by collaborative construction of compost bins using a STEAM approach with community members. Visiting classes joined workshops and were encouraged to adopt the project. The initiative fostered early awareness of sustainability and community involvement.

Pollution in a Wetland – Cyprus. Set in a national park, students investigated water pollution in an artificial lake. Activities varied by age, from observing aquatic life to measuring oxygen levels and algae. Pupils collaborated with teachers and other experts to test NBS such as filtering vegetation and species introduction, and presented findings to agronomists. The project promoted stewardship, critical thinking, and advocacy while preparing students for active sustainability roles.

Practical Implications - Lessons Learned and Future Guidance for Implementing Nature-Based Solutions in Schools. The interviews also served to gather advice for future project implementers. The summarized key findings are as follows:

Planning and Implementation. Implementing Nature-Based Solutions in schools requires clear objectives, early engagement of stakeholders (students, teachers, families, authorities, experts), and a detailed plan with tasks, timelines, resources, and responsibilities. Securing funding, materials, and expertise early on is key, as is staying flexible through ongoing monitoring.

Student Participation. Active involvement is central to success. Project-Based Learning, outdoor activities, and motivational elements like workshops and contests engage students and foster ownership.

Family Involvement. Families enhance impact through informational campaigns, events, and volunteer activities. Barriers like time constraints can be addressed with flexible options and clear communication of the benefits.

School Staff Engagement. Teachers and staff are crucial and should be part of a motivated, collaborative team. Regular meetings, professional development, recognition, and shared achievements support long-term commitment.

Practical Tips and Advice. Start small and expand gradually. Using existing programs (e.g. Eco-Schools) offers valuable structure and support.

Empirical Data Collection. Monitoring biodiversity, plant growth, and student engagement provides essential insights into ecological and educational outcomes.

Encouraging Broader Participation. Involving the wider community - local organizations, businesses, and volunteers - strengthens projects. Outreach via social media, signage, and events, along with meaningful roles, builds shared ownership and commitment.

Discussion

This article has explored the educational potential of combining Nature-Based Solutions, citizen science, and youth activism as complementary pillars of climate education. Grounded in theory and informed by eight diverse case studies from across Europe, the analysis demonstrates that such integrative approaches can lead to meaningful outcomes, enriched pedagogical practices, and empowered student agency. The interviews demonstrate that NBS projects should be embedded within a planned, participatory and reflective educational framework in order to realise their full potential. However, the success and longevity of such projects depend on thoughtfulness. Sustainability is not an automatic result of green aesthetics or well-intentioned enthusiasm. Rather, it must be deliberately cultivated through inclusive practices, cross-sectoral collaboration, and sustained support structures. These projects provide opportunities for students to engage as scientists, stewards, and citizens - roles that align with the broader aims of Education for Sustainable Development (e.g. SDG13 “Take urgent action to combat climate change and its impacts”, UNESCO, 2017, p.36). In conclusion, NBS projects - when developed with pedagogical care, critical consciousness, and democratic participation - can serve as effective, long-term living laboratories for climate education.

Limitations. The findings presented in this article are based on a limited set of data and should therefore be interpreted with caution. While they offer valuable insights, they reflect individual perspectives and specific contexts rather than broad, generalizable trends.

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PD facilitators: roles and challenges

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Keywords: role of educators, roles, beliefs, PD sessions, upscaling

Design principles of content-related professional development (PD) courses for in-service mathematics teachers have become a vivid research area. Although facilitators play an important role in scaling up PD programs (Jackson et al., 2015), research on the relevant processes is rare. In particular there is a lack of research into competences and strategies that facilitators need to provide rich learning opportunities for other teachers (Borko et al., 2014). Consequently, this study focuses on the facilitators' role in the implementation of a PD program on differentiation in heterogeneous classrooms. The aim is to examine how PD facilitators perceive their own role as educators and facilitators in connection to their beliefs and goals. Among others in this project, the main research questions addressed here are:

How do facilitators see their specific role as educators and do they notice any challenges or requirements for improving their professional work?

The sample for this study consists of ten mathematics teacher facilitators who all have several years of experience in teaching and teacher training. Semi-structured interviews were coded using qualitative methods based on grounded theory. PD facilitators were asked how they design content-specific learning pathways for their PD sessions in relation to their beliefs concerning the teacher PD level. They were also asked about their views of their own role as educators and specific/their goals in PD sessions, and about their perception of their own competences.

The results show that all facilitators considered appropriate learning activities and settings to be of major importance in prioritizing various adaptations of PD content resources. Facilitators mentioned several issues (e.g. community and context) taking into account holistic challenges and multi-facet complexities of their PD sessions. Using research based textbooks and hands-on material was a major facilitator goal and challenge to support in-service teachers with different forms of knowledge. Participants see themselves as mentors providing impulses for innovations rather than being problem solvers or process helpers. This is consistent with their beliefs on their role as facilitators. Overall, the results suggest that further connections between facilitators' competences, their role in adult education, their self-perception, beliefs and efficacy should be identified in future research.

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Exploring ChatGPT's Mathematical Modelling Capabilities: A Case Study

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Keywords: artificial intelligence; math education; STEM education; mathematical modelling; real-life contexts

Abstract

This study investigates the mathematical modelling capabilities of ChatGPT, focusing on three versions, GPT-3.5, GPT-4, and GPT-4-MM, and their performance on modelling tasks varying in complexity and openness. Five real-world tasks were selected based on established frameworks in mathematics education, each requiring the models to engage in key phases of the modelling process such as understanding, simplifying, mathematizing, and validating. Using standardized prompts and a deductive content analysis approach, we evaluated the quality of each model's output according to a set of modelling competencies. Findings indicate that all versions of ChatGPT are capable of solving basic mathematical problems and simpler modelling tasks. However, as task complexity increased, clear differences emerged: GPT-4 and GPT-4-MM demonstrated more advanced reasoning and a greater ability to incorporate contextual information and necessary assumptions than GPT-3.5. Despite this, none of the models exhibited strong reflective competencies or the ability to critically assess or revise their own solutions. These insights highlight both the potential and current limitations of large language models in supporting mathematical modelling within STEM education. While ChatGPT can serve as a valuable support tool, especially for routine tasks or as a basis for classroom discussion, it should not replace student reasoning. To use AI meaningfully, educators must be equipped with strategies to integrate these tools critically, supporting student autonomy, reflection, and problem-solving skills.

Introduction: Purpose and importance

Mathematical modelling is pivotal in STEM education, bridging theoretical concepts and real-world applications. It fosters critical thinking and problem-solving skills by enabling pupils to analyse and address complex problems through mathematical principles (Kaiser et al., 2013). Despite its benefits, modelling tasks are not routinely integrated into daily mathematics teaching (Blum, 2002; Maaß and Gurlitt, 2009), highlighting the need for innovative approaches to lesson design.

In the digital era, tools like AI-driven systems, such as GPT-3.5 and GPT-4, offer new possibilities for enhancing STEM education. These systems can solve mathematical problems of varying complexity, providing insights into human–AI interactions and their potential impact on teaching and learning. However, their capabilities in addressing advanced mathematical modelling tasks remain under scrutiny. Understanding their strengths, limitations, and evolution is essential for leveraging AI effectively in education.

This study investigates the mathematical modelling competencies of GPT systems, focusing on how these tools handle tasks with varying openness and complexity. Key research questions include comparing the performance of GPT-3.5 and GPT-4, and identifying their specific strengths and weaknesses. By exploring these aspects, we aim to illuminate the potential of AI in STEM education while addressing challenges like the digital divide and fostering innovative teaching practices.

Theoretical Background

Mathematical Modelling

Mathematical modelling bridges real-world problems and abstract solutions through a structured process of simplification, mathematization, and validation (Henn, 2000; Niss, Blum and Galbraith, 2007). It supports diverse educational goals, such as developing problem-solving skills, fostering positive attitudes toward mathematics, and engaging with socially relevant issues (Maaß, 2004; Kaiser and Sriraman, 2006). While rooted in mathematics education, it is increasingly understood as a key transdisciplinary competency that serves as a bridge to integrated STEM education (Kertil et al., 2016).

Effective modelling requires competencies across all process stages, including meta-cognitive skills and reasoning (Maaß, 2004; Blomhøj and Jensen, 2007). Tasks range from routine problems to complex scenarios, so it is important to have a classification for these tasks, like Blomhøj and Jensen (2003) or Büchter and Leuders (2005). We refer to the classification scheme for modelling of Maaß (2010).

Background of AI

The rise of AI tools like ChatGPT has opened new possibilities in mathematics education, supporting tasks such as problem-solving and personalized learning (Chassignol et al., 2018; Zhang and Aslan, 2021). ChatGPT, a large language model, can handle tasks ranging from basic calculations to solving integrals and differential equations, with GPT-4.0 outperforming GPT-3.5 on standardized tests like the Math SAT (Helfrich-Schkarbanenko, 2023; OpenAI et al., 2023).

However, its effectiveness depends on task complexity, and concerns remain about biases, over-reliance, and reduced student autonomy (Lin et al., 2023; McGee, 2023). Despite these challenges, ChatGPT offers valuable opportunities for enhancing education if integrated thoughtfully. Understanding its limitations and capabilities is crucial for responsible use in classrooms.

Methodology

To evaluate ChatGPT's modelling competencies, five tasks of varying complexity and openness were selected based on established frameworks for modelling tasks (Maaß, 2010). The tasks included scenarios such as determining whether a fuel-saving trip is worthwhile and calculating the time required for water distribution during a traffic jam. These tasks were designed to reflect real-world contexts and required assumptions and validation, allowing for an in-depth assessment of AI performance. Table 1 shows the characteristics of the five modelling tasks.

Table 1.
Characteristics of modelling tasks

	Data	Nature of relationship to reality	Type of representation	Open-ness of Task
Task 1: Rubber ball	matching	embedded; intentionally artificial	text	ascertaining task
Task 2: Ferry price	missing	embedded	text	ascertaining task
Task 3: Refueling	missing	authentic; close to reality	text; picture; situation	ascertaining problem
Task 4: Water supply	missing	close to reality	text; situation	ascertaining problem
Task 5: Round up	superfluous and missing	authentic	text; situation	ascertaining problem

Note. For a description of the categories, see Maaß (2010).

Each GPT version was instructed to solve these tasks following a standardized prompt to minimize external influence on the results. The solutions were then evaluated based on eight competencies of the modelling process, including understanding, simplifying, mathematisation, and validation (Greefrath and Maaß, 2020). Ratings

were assigned to each competency to compare the performance of the three AI versions. For this, we conducted qualitative content analysis (Mayring, 2000) using a deductive approach to organize and analyse the solutions of GPT based on the competencies of (Greefrath and Maaß, 2020). Three separate coders individually evaluated the solutions, and several methods (e.g., Gwet's AC (Gwet, 2008)) were employed to gauge the reliability and agreement among the coders.

Findings

The findings revealed that ChatGPT demonstrates basic mathematical problem-solving skills and partial modelling competencies, but its performance varies significantly across task complexity and openness. All three versions provided accurate solutions for simple tasks, such as calculating costs for a ferry ticket. However, as task complexity increased, significant differences emerged.

For instance, in the task requiring a cost-benefit analysis of a trip to a cheaper fuel station, GPT-3.5 produced an incorrect solution due to oversimplification, whereas GPT-4.0 and GPT-MM incorporated assumptions about fuel consumption and travel distance to deliver accurate results. Similarly, in the task involving water distribution during a traffic jam, GPT-4.0 and GPT-MM demonstrated a better grasp of contextual elements, such as estimating the number of vehicles, compared to GPT-3.5, which failed to account for missing data and contextual factors. Across tasks of moderate complexity, GPT-4.0 and GPT-MM outperformed GPT-3.5 in terms of accuracy and contextual integration.

Nevertheless, all versions displayed superficial levels of reflection, with limited capacity to critically evaluate or revise their own solutions. This shortcoming persisted even in scenarios that required integrating environmental or temporal considerations, underscoring current limitations in AI-driven modelling reasoning.

Implications for STEM Education

Given these findings, several educational implications emerge that are relevant for STEM Education in general, since mathematical modelling is a necessary competency not only in all STEM disciplines but also in interdisciplinary approaches such as integrated STEM education. While GPT tools demonstrate the ability to solve simple modelling problems and perform routine mathematical tasks, their limitations in handling complex, authentic modelling scenarios must be taken seriously. If used uncritically, there is a risk that students might over-rely on AI tools, which could impede the development of critical thinking and independent problem-solving skills, both essential competencies in STEM education.

STEM educators therefore require targeted professional development to critically engage with these tools and to integrate them meaningfully into their pedagogical practice. AI models such as ChatGPT should be positioned as supplementary rather than primary problem solvers in the classroom. Used appropriately, their limitations offer valuable learning opportunities. For example, by encouraging error analysis or fostering discussions on how AI systems function. Most importantly, the instructional use of AI must continue to emphasize student autonomy, reflection, and analytical reasoning beyond what current AI systems can provide. Integrating AI in education requires a balanced approach, combining the strengths of digital tools with the pedagogical goals of fostering critical thinking and creativity.

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Testing Digital On-Demand Support and Multimedia for Developing Experimentation Competencies

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Abstract

A key goal of climate education in schools is students' development of climate literacy. In this regard, experimentation competency relates to climate literacy. However, due to the inherent complexity of the experimentation process, fostering this competency is challenging. Given the variety of students' heterogeneous learning prerequisites, digital environments have the potential to support learning through multimedia design and scaffolding. Although theoretical foundations suggest the benefits of both scaffolding and multimodal learning, there is empirical evidence for digital implementations, particularly in individual learning contexts. The present study investigated the effects of digital on-demand instructional support (ODIS) and multimedia instruction on sixth graders' experimental performance.

Using a 2 x 2 experimental field study design, 327 German sixth graders from 17 schools were randomly assigned to four conditions: text-based or multimedia instruction, with or without access to ODIS. Students completed hands-on experiments independently, guided by a digital learning environment. The experimentation process was divided into four phases: hypothesis formulation, planning, execution, and interpretation. Performance was assessed through open-ended responses (coded with substantial to excellent inter-rater reliability, $ICC = .81-.91$), as well as through automated evaluation.

Two-way ANOVAs revealed no significant effects of ODIS ($F(1, 323) = 0.27, p = .61$) or multimedia instruction ($F(1, 323) = 0.00, p = .96$) on overall experimental performance. Sensitivity analyses confirmed these null findings. However, a mixed ANOVA revealed significant performance differences across phases ($F(3, 969) = 61.20, p < .001, \eta G^2 = .11$).

These results suggest that the availability of digital ODIS and multimedia features may be insufficient. Potential explanations include suboptimal interface design, non-use of ODIS, and mismatches between the support offered and student aptitude. Future research should examine actual ODIS usage patterns as well as differential effects and optimize digital learning environments. In terms of didactic implications for de-

signing digital learning environments, simply providing students with ODIS, videos, and audio files is not sufficient to enhance performance.

Introduction

The purpose of climate education in school is to foster students' climate literacy by equipping them with knowledge and skills necessary to effectively contribute to societal efforts to address the global climate crisis (Stadler et al., 2024). One aspect of climate literacy is the ability to acquire and evaluate empirical research findings, giving students an understanding of how scientists conduct climate research and draw conclusions about climate change. This includes also the ability to generate, process and interpret questions and hypotheses, which is part of experimentation competency.

Challenges in Developing Experimentation Competencies

Due to the inherent complexity of the experimental process, fostering experimentation competency is a significant challenge (De Jong and van Joolingen, 1998, Zimmerman, 2007). The process comprises several interconnected phases, each of which requires specific skills and abilities. Therefore, each phase presents its own potential challenges (De Jong and van Joolingen, 1998). To address this complexity, we structured the experimentation process into four distinct phases - hypothesis formulation, planning, execution, and interpretation - consistent with established inquiry frameworks (Pedaste et al., 2015). Separating planning from executing is crucial because experimental design requires different cognitive processes and skills than execution (Chen & Klahr, 1999).

Additional guidance can be provided through on-demand instructional support (ODIS), which provides progressive hints that increase in specificity when requested by learners (Wood & Wood, 1999). While ODIS has shown positive effects on learning outcomes in paper-based group settings (Arnold et al., 2016) and these implementations may have benefited from the social scaffolding that is inherent in collaborative work. However, help-seeking can be hindered by concerns about social evaluation, particularly regarding students with performance orientation (Karabenick & Gonida, 2018). Digital learning environments can address this barrier by providing anonymous, immediate access to support. Nevertheless, it remains unexplored whether the option to access digital ODIS is equally effective in individual learning contexts. Therefore, the present study examines the effectiveness of digital ODIS on experimental performance in individual learning settings.

Digital learning environments offer the opportunity to vary the presentation of learning materials, providing students with multimedia instruction. According to the multimedia principle, learning with words and pictures is more effective than learning with words alone (Mayer, 2022a). This can reduce cognitive load by utilizing both visual and auditory processing channels (Mayer, 2022b). However, the effectiveness of multimedia versus text-based instruction depends on learner characteristics: Learners with

lower prior knowledge may benefit from the reduced decoding demands of multimedia, whereas this effect is less pronounced for students with higher prior knowledge (Mayer, 2022b). Recent studies, however, find no consistent main effects between modalities (Tarchi et al., 2022), suggesting that factors beyond presentation format influence learning outcomes.

While the effects of paper-based ODIS on learning outcomes have already been empirically investigated, there is currently no evidence regarding the application of digital ODIS, either in text-based or multimedia modes. In light of the increased use of digital technology in classrooms and the emphasis on evidence-based teaching, the present study seeks to address this research gap concerning digital ODIS by answering two research question: (1) Do students' overall experimental performances differ across the four experimental conditions (text vs. multimedia and ODIS vs. no ODIS)? (2) Are there effects of the condition on performance in particular phases of the experimentation process?

Method and Design

To address these research questions, we used a 2 x 2 experimental field study design (see Figure 1) with a sample of $n = 327$ 6th graders ($M_{age} = 11.89$, $SD = .68$; 55.9 % female) from 17 German schools at different tracks (5 comprehensive-track schools, 4 academic –track schools, 6 intermediate –track schools, 3 basic/vocational-track schools). Students completed a pretest one week before the intervention. During the intervention, students were randomly assigned to experimental conditions by selecting pre-configured workstations. After a brief training session on the digital learning environment, students independently completed two climate change experiments from different STEM disciplines (biology, mathematics, physics, and technology). Students worked at their own pace; processing time was logged.

		Instructional Mode	
		Text	Multimedia
ODIS	With ODIS	EG1: Text with ODIS	EG3: Multimedia with ODIS
	Without ODIS	CG: Text without ODIS	EG2: Multimedia without ODIS

Figure 1. Experimental 2 x 2 Design Combining Instructional Mode and ODIS.

Division of the experimentation process

We structured the experimentation process into the following four steps to reduce complexity, as suggested theoretically: 1. Formulating a hypothesis, 2. Planning the experiment, 3. Conducting the experiment, 4. Analysis and interpretation of the results. This division was achieved through the digital learning environment.

Performance measurement

Each phase included a task that was typical of that phase, preceded by the necessary information for that task, and with an input field in an open response format. Students had to enter their responses into these input fields and secure them by clicking the 'Confirm' button. To gain a performance measure on each task, the responses were scored using a coding scheme that was initially developed based on theoretical assumptions and then refined based on insights gained during the coding process. Interrater reliability was substantial to excellent ($ICC = .81-.91$, $\kappa = .68-.78$). The results of the measurements taken during the conducting phase were automatically evaluated using a standardized R script that compared documented values against expected ranges (0-2 points). Since the maximum number of points varied by phase, the scores of each phase were transformed into a common 0-100 metric to ensure equal weighting of each phase. Overall experimental performance was calculated as the mean of the four transformed phase scores, which served as the primary dependent variable.

Design of presentation mode and ODIS

The experimental variation consisted of (1) presentation mode: multimedia (with stop- and-replay videos and audio narrations) vs. text-based instruction, and (2) ODIS access: Students in ODIS conditions could access three levels of support (hints with conceptual knowledge, three examples including one correct solution, and complete solutions with explanations). ODIS support was provided sequentially, except during the conducting phase when all levels were available simultaneously. It was accessible via clearly labelled links in the interface.

Results

Main Analysis: Overall Performance (RQ1)

Table 1 shows the means and standard deviations of overall experimental performance across the four experimental conditions. Students were balanced across the conditions. With approximately 80 participants per condition, the study had adequate power ($>.95$) to detect effects of size of $f = 0.20$. Visual inspection revealed minimal differences between conditions, with mean scores ranging from 43.70 to 45.83.

Table 1

Means and Standard Deviations for Overall Experimental Performance and Condition

Condition	Overall Performance		
	<i>n</i>	<i>M</i>	<i>SD</i>
Text without ODIS	84	43.70	16.64
Text with ODIS	85	45.83	19.75
Multimedia without ODIS	77	44.86	20.37
Multimedia with ODIS	81	44.91	19.25

A two-way ANOVA revealed no significant main effects of ODIS ($F(1, 323) = 0.27$, $p = .605$, $\eta G^2 = .001$) or presentation mode ($F(1, 323) = 0.00$, $p = .956$, $\eta G^2 < .000$), and no significant interaction effect ($F(1, 323) = 0.25$, $p = .621$, $\eta G^2 = .001$). Sensitivity analyses, including cases with at least three scores ($n = 508$) yielded similar results, confirming robustness. The availability of ODIS and multimedia instruction did not change students' experimental performance.

Phase-Specific Analysis (RQ2)

Table 2 shows the means and standard deviations for performance by phase and condition. A visual inspection revealed that students scored the lowest during the planning phase. Additionally, it was found that mean performance differed between phases, though not consistently across all phases.

Table 2

Means and Standard Deviations for Performance by Phase and Condition

Phase	Text		Multimedia	
	without ODIS	with ODIS	without ODIS	with ODIS
Hypothesis	49.60 (25.08)	53.53 (26.74)	50.22 (27.37)	54.53 (27.52)
Planning	30.55 (28.44)	30.59 (26.33)	23.81 (29.55)	28.60 (27.03)
Execution	55.36 (34.73)	52.94 (38.07)	59.09 (33.17)	56.17 (33.90)
Interpreting	39.28 (28.42)	46.27 (33.37)	46.32 (37.13)	40.33 (34.45)

A mixed ANOVA revealed a significant main effect of phase ($F(3, 969) = 61.20$, $p < .001$, $\eta G^2 = .105$), indicating that performance differed substantially across phases: Students scored lowest during the planning phase. However, no significant interaction between condition and phase was observed ($F(9, 969) = 1.14$, $p = .332$, $\eta G^2 = .007$).

Discussion

This study investigated the average main effects of availability of digital ODIS and multimedia instruction on sixth graders' experimentation performance. Using a 2x2 experimental design, we found no significant effects on students' experimental performance. The lack of main effects suggests that support design, prior knowledge, and self-regulation interact in a complex way. If learners do not have strategies for using these resources in a targeted manner, the mere presence of digital scaffolds or the kind of presentation of the material is sufficient to influence learning performance. However, these results contrast with prior research showing benefits of paper-based ODIS (Arnold et al., 2016), in which support materials were visibly placed on workspaces and students worked collaboratively. Digital implementation and individual work settings may require different design approaches. Our study also has some limitations: First, students' prior knowledge in the content domains was not assessed, which may have influenced performance across conditions. Second, technical constraints in the learning environment (e.g., placing ODIS away from task descriptions) may have reduced the visibility and accessibility of support. Third, our study was based on a sample of Year 6 students from German schools, and the findings are based on a unique intervention. Future research should therefore analyze log data on actual ODIS usage patterns and examine potential fatigue effects from extended task duration as well as differential effects for students with heterogeneous background characteristics.

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Construction of Polygons with Scratch and Computational Thinking

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Keywords: Computational Thinking, Beliefs, Mathematics, Computer Science, Geometry, Scratch

Abstract

Concrete connections between the didactics of mathematics and computer science are rarely mentioned and are infrequently addressed in teaching. In many areas of Germany, computer science is a school subject in grades 5 and 6 or is occasionally included in mathematics lessons. This study explores the interdisciplinarity of mathematics and computer science in connection with students' computational thinking activities from a practical and scientific perspective. The study was conducted with 50 students in Grade six using Scratch to explore the structures of equilateral polygons and introduce . Quantitative studies were conducted using questionnaires to assess mathematical and computer science beliefs before and after the teaching sequence. The student solutions to the tasks included programs created with Scratch, including comments on the program's functionality and mathematical insights in the notebook. The study showed that the use of programming with Scratch in grade 6 mathematics classes have a positive effect on students' mathematical skills via computational thinking and helps them recognize the importance of mathematics and computer science for each other.

Introduction

Computer science (CS) as a school topic is of great importance and it is no longer possible to imagine education at school and university without it. CS is even taught in primary schools and at lower secondary level (Falloon, 2024). In recent years, the importance of computational thinking (CT) has become increasingly relevant, not only for computer science education but also in various areas (Payne, Tawfik & Olney, 2022).. CT is included in various curricula (Ayfer, Impagliazzo & Laxer, 2010; Falloon, 2024), can be seen as a component of the basis of CS (Xu and Zhan, 2021) and is connected to each STEM discipline (Payne, Tawfik & Olney, 2022). CT can be understood as significant for learning processes in mathematics, not least because parallels can be found between problem solving in CS and problem solving in mathematics (Büscher, 2024).

In various federal states in Germany, the subject of CS has been introduced in grades 5 and 6. Frequent use of the programming environment Scratch in conjunction with CT makes it possible to create links between mathematics and CS.

The author developed and tested teaching material using Scratch about topics traditionally included in the curricula of grades 5 and 6 (Stoppel, 2026). Based on the cre-

ation of comments in Scratch, additional notebooks, and learning diaries, the material promotes learning CT and its application to mathematics in order to grasp and understand basic mathematical structures of geometry.

In this article, we describe and analyze the results of students of grade six working on the designed tasks and analyze the changes in their beliefs about the importance of mathematics and computer science for each other when working on problems in mathematics and computer science connected with CT.

Theory

CT uses mathematical thinking for problem-solving (Korkmaz et al., 2015) and can be seen as significant for learning processes in mathematics (Büscher, 2024). It includes concepts such as decomposition, pattern recognition, abstraction, and algorithmic thinking (Wing, 2006). Over several years CT has become increasingly recognized as essential not only in computer science but across disciplines, including mathematics. CT is a component of the basis of computer science, is connected to all STEM disciplines and can motivate students to study STEM-related majors (Payne et al, 2022; Xu and Zhang, 2021).

Mathematics is the basis for learning programming (Kayhan et al., 2024; White, 2003). Taylor et al. (2010) pointed out that programming improves mathematical thinking, Jimenez et al. (2021) noted that learning programming increases students' mathematical competencies. Several studies suggest links between students' self-efficacy in programming and their mathematical competencies (Kayhan et al., 2024; Lee et al., 2024). CT can be understood as an epistemic practice and might be predicted based on students' epistemological beliefs (Bowden, 2019), so that it is appropriate to examine CT and students' beliefs.

By Stoppel (2019) it is useful to distinguish between general epistemological beliefs and subject-specific beliefs in STEM. He notes that a distinction between epistemological beliefs and mathematical beliefs is useful to be able to concentrate on subject-specific aspects. When considering subject-related beliefs for different STEM subjects, epistemological beliefs should nevertheless not be ignored to be able to investigate connections between subject-specific beliefs of different STEM subjects. As Lee et al. (2024) noted some perspectives from beliefs in mathematics can be transferred to computer science and vice versa; connections can be drawn between them.

In many disciplines, programming is already an integral part of knowledge and cognitive processes (Weintrop et al., 2016). This also offers opportunities for mathematics education (Büscher, 2014; Misfeldt & Ejsing-Duun, 2015). Especially learners can explore mathematical concepts in more detail through programming (e. g. b. Büscher, 2014).

Comments in a program provide a way to explain how the code works. They can be used to describe what certain sections of the program code mean (Technologieexperten, 2025).

Design of the study

By Lee et al. (2024), Stoppel (2019) and the descriptions above, programs of Scratch and their mathematical description stand in relationship with each other, subject-specific beliefs and represent CT (figure 1). In programming, in addition to coding and comments in the program, are also functional components. With Scratch, this is characterized by graphical representation. To draw a figure, students can use commands to control the pen's movements, draw figures, and explore their structures (Förster, 2015).

Computational thinking can be recognized both in the comments within a program and in the mathematical considerations. Students' beliefs can be understood as a connection between programming and mathematics, thereby forming a link between programming and computational thinking. The connections are represented in figure 1 for our purposes.

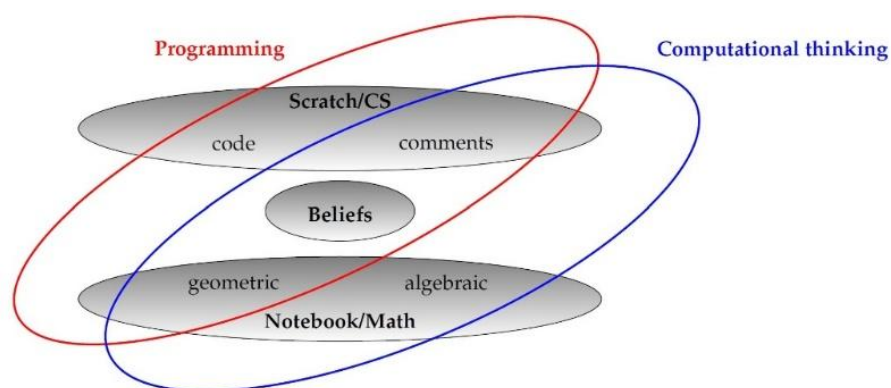


Figure 1. Connections between components of the study

Computational thinking can be understood as an epistemic practice and can be predicted based on students' epistemological beliefs (Melander Bowden, 2019). This applies to this study, as it is conducted for both mathematics and computer science.

The structure, formulations, and interpretation of results by Kloosterman and Stage (1992) can largely be transferred from mathematics to computer science to draw connections between mathematics and computer science. The study of Hofer and Pintrich (1997) is not directly connected to mathematics and computer science, but describes connections between mathematics and computer science.

Based on the considerations above, the questionnaire is designed according to Hofer and Pintrich (1997), Kloosterman and Stage (1992) and Lee et al. (2024). Its category

ries considered here are the “importance of mathematics for programming” (MP) and the “importance of programming for mathematics” (PM) scaled from 1 to 5.

The study of regular polygons is a part of mathematics instruction in secondary school. Scratch is often used in grades 5 und 6 and students are able to use it. The teaching material is based on the grade mathematics and computer science curriculum and designed by the author. The worksheets used in the study are published in Stoppel (2026).

For the study, data was collected from 50 sixth-grade students in mathematics and computer science. The students' subject-specific background was virtually identical when completing the assignments. The author led the class lessons together with the regular teachers of the classes.

The data collection began with the pretest questionnaire (Q1). Immediately following, the students worked out the worksheets in the following 90 minutes. The second questionnaires (Q2) were completed two or three days later.

The students received worksheets with the tasks and a notebook to notate the mathematical components of the solutions. Descriptions of the computer science structures of the programs were recorded as comments within the self-written Scratch programs. The students saved the Scratch programs on the school server, from which the teachers could copy them.

Results

Table 1 shows the absolute frequencies of beliefs in the Importance of Mathematics for Programming (MP) for Q1 and Q2. Each column contains the absolute frequencies of the beliefs in MP in the specified interval. For Q1, 14 students exhibit beliefs “in the middle,” i.e., for . Only one student has higher beliefs in the MP. The remaining eight students have only low beliefs in the necessity of MP. The situation changed significantly from the first to the second questionnaire. The absolute frequency of low determination decreased; the corresponding beliefs up to were held by 11 students. Only three students still had a low conviction in the necessity of mathematics for computer science.

Table 1

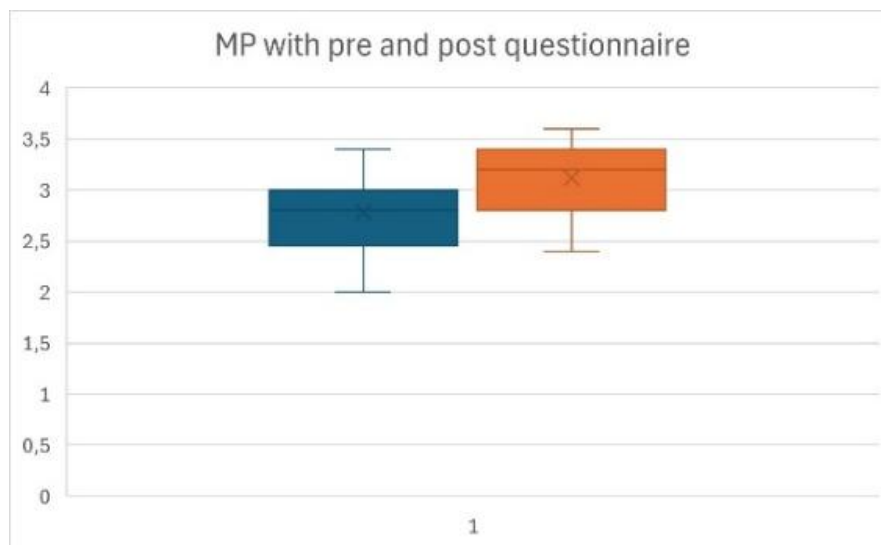
Absolute frequency of beliefs in MP in intervals for Q1 and Q2

	[1, 2]	]2, 2.25]	]2.25, 2.5]	]2.5, 2.75]	]2.75, 3.25]	]3.25, 3.5]	]3.5, 3.75]	]3.75, 4]	]4, 5]
Q1	1		5	3	14	1			
Q2			2	1	10	7	4		

The contents of Table 1 are presented as boxplots on the left side of Figure 1. This shows significant changes in the distributions of the beliefs in MP during the exercises. Beliefs in the MP have increased significantly, both in the mean and in the quantiles.

The changes from pretest to post test for individuals are visible on the right side of Figure 1. The beliefs in MP before the lessons are plotted on the -axis, and after the lessons on the -axis. In the case of an increase in beliefs, the points lie above the line ; in the case of a decrease in beliefs, the points lie below this line. The figure shows that the beliefs in MP increase for most of the students, even strong increases are noticeable among many students.

The effects of the workout of the exercises on beliefs in PM are stronger than on beliefs in MP, see Table 2. In the pre-test, all students, with one exception, already showed “neutral” beliefs of $]2.75, 3.25]$ or higher beliefs in PM. Nevertheless, strong changes in beliefs were evident from Q1 to Q2. As before, only one student had beliefs in $PM \leq 2.75$; however, they were not far below the neutral range than in Q1. In Q2, only six students’ beliefs were in the neutral range. The other students had stronger beliefs in PM. Only the two highest assessments, which were not present at all in the first test, contained the beliefs of seven of the students. This demonstrates a very strong effect of the workout of the exercises on the students.



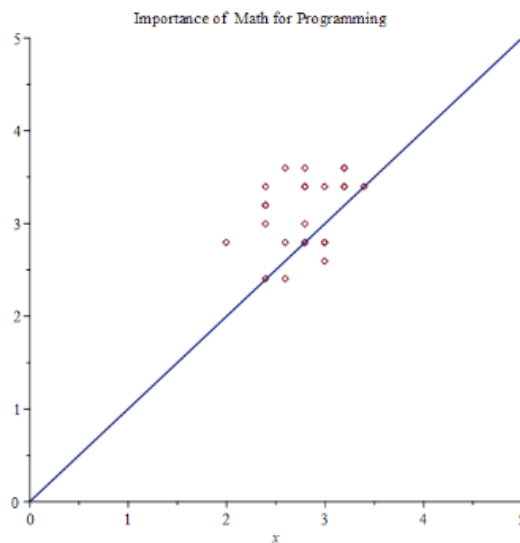


Figure 2. Boxplot of beliefs in MP in Q1 (blue) and Q2 (orange), left, relationships between them, right (: Q1; : Q2)

The boxplots on the left side of Figure 3 indicate that in the case of beliefs in PM, an increase is visible. As can be seen on the right side of Figure 3, the beliefs in PM of many students increase, and for some students, beliefs in PM decrease. The decrease of the beliefs is not surprising, since the values for PM beliefs were already high in Q1.

The results of the study demonstrate a positive effect of CT for the teaching sequence in just four lessons. It is evident that the use of Scratch to address mathematical problems quickly led to an understanding of the necessity of mathematics for computer science and computer science for mathematics.

Table 2

Absolute frequency of beliefs in PM in intervals for Q1 and Q2

	[1, 2]	]2, 2.5]	]2.5, 3.2]	]3.2, 3.5]	]3.5, 4]	]4, 5]
Q1	1		12	6	4	
Q2			1	6	6	4 4 3

Conclusions

The results of the study show, that connections between mathematics and programming can be made clear to students through computational thinking. Students assume mathematics as support for computer science or computer science as support for mathematics. This enables students to draw conclusions from computer science to mathematics and vice versa. These positive effects should be investigated more closely.

The study was short so far. It needs to be investigated whether the effects are also visible over a long time. Will these effects also appear in other digital media and other topics?

The question about the causes of changes in beliefs arises. Finding an answer requires a look at comments in the programs and students' notebooks, which are taking place.

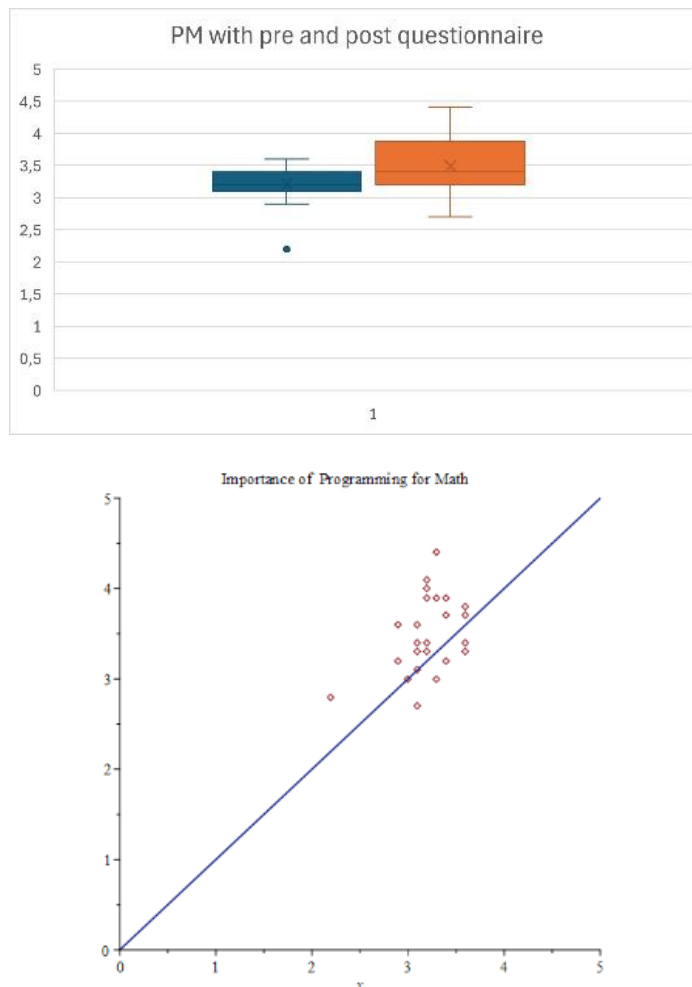


Figure 3. Boxplot of beliefs in PM in Q1 (blue) and Q2 (orange), left, relationships between them, right (: Q1; : Q2)

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STEM Education in Europe: Insights into national Trends, Best Practices, and Missed Opportunities

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Keywords: STEM, STE(A)M, Trend Analysis, Interdisciplinary STEM education, Qualitative Analysis

Abstract

STEM education is a European priority, but its implementation remains fragmented. While numerous EU-funded initiatives promote innovative, integrated STE(A)M approaches, their influence on national education systems is unclear. This paper investigates the tension between international innovation and national uptake. We analyse (1) the status of national STEM policies and (2) the perceived influence of international initiatives on them.

We conducted a qualitative study with senior policy drivers from eight European countries. Findings show that national STEM implementation is uneven and hindered by systemic barriers, particularly teacher shortages and fragmented curricula. International initiatives are valued for providing resources and methodological impulses. However, their long-term integration into national systems remains a significant challenge, often failing to achieve systemic scale. We conclude that bridging this gap between international innovation and national policy is essential to leveraging the transformative potential of STEM education.

STEM Education in Europe

STEM education has become a central priority in international education discourse, driven by its relevance for economic growth, innovation, and addressing societal transformations such as rapid digitalization and climate change. It is widely regarded as a key enabler of competitiveness and innovation capacity (Bacovic et al., 2022) and is expected to foster 21st-century skills such as critical thinking, creativity, and collaboration (Marrero et al., 2014; Vuorkari et al., 2022). These transversal competencies are seen as prerequisites for full participation in democratic, knowledge-based, and technology-driven societies.

Despite this growing attention, the concept itself remains inconsistently defined. In the academic literature, STEM education is interpreted along a broad continuum ranging from traditional, subject-oriented approaches to multi-, inter-, or even trans-disciplinary models (Breiner et al., 2012; McComas & Burgin, 2020; Bybee, 2013). In order to distinguish these different approaches, the concept of integrated STEM was introduced to differentiate interdisciplinary models from purely subject-specific ones.

Several frameworks have since been proposed to structure such integrated approaches to STEM education. Kelley and Knowles (2016), for example, define integrated STEM as the coordinated teaching of two or more STEM disciplines, embedded in authentic contexts. Thibaut et al. (2018) emphasize the importance of real-world relevance and instructional coherence in designing integrated STEM learning environments. Depending on the source, further aspects are considered essential for integrated STEM education. These include the use of inquiry-based or project-based learning approaches, a focus on specific skills such as problem solving and critical thinking, and, in some cases, the inclusion of non-STEM subjects.

In recent years, the acronym has frequently been expanded to STE(A)M, incorporating 'Arts' or creativity, though this term is often used without a specified definition or consistent implementation (Aguilera & Ortiz-Revilla, 2021; Spyropoulou & Kameas, 2024). Given this ambiguity, and because both 'Integrated STEM' and 'STE(A)M' are used to describe the innovative, non-traditional approaches found in the international initiatives this paper investigates, we draw on Straser et al. (2025) to propose a simplified unifying working definition: Integrated STEM or STE(A)M education refers to the combination of at least two subjects, including at least one STEM domain, into a joint learning experience. This experience may be enriched by pedagogical approaches such as inquiry-based, project-based, or design-based learning, and is often framed by 21st-century competencies such as creativity, collaboration, and problem-solving, with an emphasis on real-life contexts.

While these conceptual models are ambitious, it remains an open question to what extent they are reflected in practice. This question becomes particularly urgent given the wealth of European initiatives. A comprehensive analysis of 860 EU-funded STEM initiatives (Straser et al., 2025) found a strong alignment with these integrated models: most projects are interdisciplinary, use innovative pedagogies (e.g., inquiry-based learning), and respond to societal challenges. Given the scope and thematic relevance of these projects, they offer considerable potential to support educational innovation and, in the medium term, to contribute to a systemic shift, from traditionally subject-focused STEM education towards more integrated and interdisciplinary STE(A)M approaches. However, the mere existence of these international resources and their potential for innovation does not guarantee their uptake or systemic anchoring at the national level. It remains unclear whether this international momentum translates into national policies and curricula or remains fragmented. Against this back-

ground, it becomes essential to examine how these developments are reflected and taken up at the national level. This leads to the following research questions:

RQ1: How is STEM education currently addressed in national policies and initiatives across European countries, and what characterises their implementation frameworks, priorities, and structural conditions?

RQ2: To what extent and in what ways do international STEM initiatives influence national policy development and educational practice across Europe?

Methodology

To investigate the role of national STEM education policies and their interaction with international initiatives, we conducted a qualitative study with policy drivers in eight European countries. In this context, we use the term policy driver to refer to individuals with a broad overview of the educational landscape in their country and with specific expertise in the development, implementation, or evaluation of STEM-related policies and initiatives. Policy drivers were typically senior stakeholders such as ministry officials, representatives of national agencies, or experts with long-standing experience in STEM education at the policy level.

As there is no centralised database providing a comprehensive overview of STEM and STE(A)M policies across Europe, this approach allowed us to gather in-depth and context-sensitive insights into the national situation. For this purpose, we designed an open-ended questionnaire that was informed by previous European Schoolnet surveys (e.g., Nistor, 2018) and adapted to current STEM-related trends. The instrument consisted of fifteen questions, structured into three main areas. In the first part, policy drivers were asked to describe the current status of STEM education in their country, including the organisation of the education system, the extent to which STEM has been integrated, and perceived barriers to further implementation. The second part focused on national initiatives, asking for examples of particularly prominent or successful programmes and strategies supporting STEM or STE(A)M education. In the third part, participants were invited to assess the perceived influence of international STEM initiatives on the national education system, in terms of inspiration, adoption of practices, or policy change.

The questionnaire was distributed digitally in two formats (online survey and editable Word file) to allow flexible participation. Each consortium partner was responsible for identifying and recruiting relevant policy drivers in their country. Where a single response did not provide sufficient coverage, additional experts were consulted to ensure a comprehensive account of the national situation. All responses were anonymised before analysis.

Data were analysed using thematic qualitative content analysis (Kuckartz, 2012). The coding framework was derived deductively from previous analyses and theoretical frameworks (e.g., Bybee, 2013; Kelley & Knowles, 2016) and extended inductively. Coding was conducted independently by two researchers, resolving discrepancies through consensus to ensure intercoder reliability and credibility.

National case studies were developed, synthesised into a cross-case analysis, and reviewed by consortium partners for factual accuracy. This expert-based approach has limitations, including potential selection bias and heterogeneity of terminology, which complicates direct comparison. However, trustworthiness was ensured by triangulating sources, systematic coding, and inter-coder consensus.

Results

The analysis of the policy driver interviews provides a differentiated picture of how STEM education is positioned within national education systems across Europe. Three major themes emerged, corresponding to the structure of the questionnaire: (1) the current status of STEM education, (2) national STEM initiatives, and (3) the perceived impact of international initiatives on national policies and practices.

Across countries, STEM education was described as a field of growing importance, but also as one that remains unevenly embedded in national education systems. In most countries, STEM is not implemented as a separate subject area but is integrated into existing disciplines such as mathematics and science. Policy drivers emphasised that systemic barriers hinder a more comprehensive implementation. These include shortages of qualified teachers, fragmented curricula, and limited opportunities for interdisciplinary approaches. Some respondents also highlighted that while STEM has been widely recognised in policy discourse, concrete integration into teacher education and school practice often lags behind.

Policy drivers identified a range of initiatives aimed at promoting STEM at national level. These initiatives varied in scope from large-scale national strategies (e.g., curriculum reforms, continuous professional development programmes for teachers) to targeted interventions (e.g., summer schools, competitions, or regional networks). A common thread across countries was the recognition that teachers play a central role in scaling STEM education. Many initiatives therefore focused on professional development and capacity building, sometimes including cross-sectoral collaborations between schools, universities, and enterprises. Nevertheless, the emphasis and maturity of initiatives differed substantially between countries: while some have institutionalised STEM education within national curricula, others rely heavily on project-based or extracurricular activities.

When asked about the role of international projects, policy drivers generally recognised their positive influence on national STEM education landscapes. International initiatives were reported to provide inspiration, methodological impulses, and ready-to-use resources. In some cases, they also served as catalysts for national reforms, for example by informing teacher training programmes or by legitimising the inclusion of interdisciplinary approaches. At the same time, respondents stressed that the impact of international initiatives is uneven: while some countries have successfully embedded project results into national frameworks, in others the influence remains limited to small networks of motivated teachers or schools. A recurring theme was the need for stronger mechanisms to ensure sustainability and transfer from international to national levels.

In summary, the results highlight a dynamic but fragmented picture of STEM education in Europe. STEM is widely acknowledged as a policy priority, yet national approaches vary considerably in their depth and scope. International initiatives are valued for their contributions, but their long-term integration into national systems remains a challenge.

Discussion and Conclusion

The findings of this study provide new insights into how STEM education is addressed at the national level in Europe and how international initiatives contribute to shaping these developments. Taken together, these insights point directly to a core tension between innovation and institutionalisation. While international projects generate valuable resources and align closely with current societal challenges, (drawing on findings that they serve as testing grounds for novel pedagogies), their integration into national systems depends on structural conditions such as policy priorities, teacher education frameworks, and available funding.

Our study highlights three key implications for the future development of STEM education in Europe. First, greater attention must be paid to systemic teacher support, as teacher shortages and insufficient professionalisation remain the most critical bottlenecks. Second, mechanisms for sustainability and mainstreaming need to be strengthened to ensure that international initiatives can have lasting effects at the national level. Third, closer coordination between national policies and EU-funded projects is essential to move beyond fragmented landscapes and towards coherent strategies that foster innovation while ensuring structural integration.

In conclusion, STEM education in Europe stands at a crossroads. The foundations for innovation are in place, supported by a wealth of international initiatives and a growing national recognition of STEM's importance. Yet without stronger systemic links between international projects and national education systems, the transformative potential of STEM education risks remaining underutilised. Future efforts should

therefore focus on bridging this gap, creating a European STEM ecosystem that is both innovative and sustainable.

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Educational leaders' perceptions of STEM education

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Keywords: teacher educators; STEM education; STEM perceptions

Abstract

The perceptions of educational leaders concerning STEM education have been explored through an analytical study of drawings and written descriptions. This research delves into how teacher educators perceive STEM education, emphasizing their depictions of STEM as a discipline, their comprehension of the nature of STEM-related teaching and learning, and the competencies of individuals who possess a STEM education. Participants were instructed to create a drawing of a STEM learning environment and to complete five statements based on five prompts regarding what STEM represents and how an individual develops personal STEM capabilities.

For data analysis, the Legitimation Code Theory (LCT) specialization codes (Maton, 2014) were utilized, comprising 198 individual response items to provide insight into participants' perceptions of STEM education. Approximately 45% of the responses aligned with the knowledge code, with around 33% indicating alignment with the knower code. The remaining responses indicated elite-code perceptions, suggesting a minority of participants valued both disciplinary knowledge and practices as well as generic skills and attributes within the STEM context. It is argued that curriculum structure and reporting requirements influence these perceptions. Further research is recommended to explore how these perceptions impact the enacted curriculum.

STEM education is typically characterized as an instructional approach integrating the disciplines of science, technology, engineering, and mathematics through open-ended, realistic, and interdisciplinary problem-solving challenges (e.g., Asghar et al., 2012). Evidence suggests this method enhances student learning outcomes in both school and university environments (e.g., Becker & Park, 2011). There remains, however, a notable imbalance in the priority given to varying forms of learning within STEM, where some educators prioritize disciplinary knowledge over the development of generic skills.

Educational leaders' perceptions regarding STEM education, emphasizing 21st-century capabilities, have been relatively understudied (Holmlund, 2018). Although misconceptions about interdisciplinary STEM education persist, including views that it reduces the complexity of science concepts or equates to 'hands-on' activities,

these misconceptions remain prevalent. Educators' perspectives diverge; some argue that STEM teachers need not have comprehensive disciplinary mastery but can co-learn with students, while others perceive STEM as a means to foster communication and teamwork. Significant concern remains regarding the potential "dilution" of discipline-specific content and practices in the context of STEM teaching and professional development activities (e.g., Winberg et al., 2019).

The present study aims to deepen understanding of how STEM education is perceived by teacher educators. Specifically, it investigates the epistemic relations (knowledge and practices related to STEM) and social relations (generic skills and personal attributes) emphasized in STEM education.

This investigation is guided by two primary research questions:

1. How do school principals and teacher educators perceive STEM education, as evidenced by their descriptions and depictions?
2. What are the implications of these perceptions for the design of STEM curricula?

The analysis is contextualized in Germany & Switzerland. Nonetheless, we believe the findings are of broader relevance, exemplifying how the methods employed can be adapted into effective and practical prompts for STEM education initiatives globally.

The research highlights educational leaders' perspectives on how STEM knowledge is viewed, understood, and discussed in academic contexts. Understanding these perceptions may facilitate integrative discourse around STEM education in educational institutions, potentially leading to a nuanced understanding of how to address issues in STEM education to achieve desired student outcomes.

The study indicates that teacher educators strongly advocate for discipline-specific knowledge mastery in STEM education approaches, supporting separate/disciplined or interdisciplinary curriculum. Common with project-related studies, global studies (e.g., Honey et al., 2014) highlight a strong influence of content mastery-based assessment/reporting, shaping schools' STEM curriculum design. Teacher educators hold this view more strongly, perhaps linked to STEM teacher program staffing/structuring, assessment, and content-heavy school curriculum/syllabi familiarity expected of graduates. Teacher educators perceived STEM learning effectiveness by discipline interconnectivity as essential for interdisciplinary projects and authentic problem-solving.

Much literature discussing the benefits of interdisciplinary STEM curricula point to advantages of learning of STEM through interdisciplinary STEM tasks for developing generic learning skills and personal dispositions, such as communication,

teamwork, critical thinking, creative problem solving and resilience and self-efficacy (e.g., Holmlund et al., 2018). In this study, we identified a diversity of perceptions amongst participants. Across the different measures, almost half the participant responses indicated *knowledge-code perceptions* with a smaller but significant number (approximately a third of responses) indicating *knowercode perceptions*. The remaining responses showed *élite-code perceptions*, indicating a small proportion of participants valued the development of *both* disciplinary knowledge/practices and generic skills/attributes in STEM education.

Our research offers valuable insights into differentially valued STEM curriculum and pedagogical aspects. While we can assume that such curricula represent effective balances of *epistemic* and *social* goals, we have achieved an understanding of what this might look in different contexts. Given the relationship between perceptions, attitudes, and *courses of action*, this research highlights the methodological significance of using our framework instrument to unearth participants' perceptions of STEM education.

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Artificial Intelligence Supported Science Mentor

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Keywords: artificial intelligence, virtual science mentor, virtual science mentor application

Abstract

This study focuses on the artificial intelligence-supported virtual science mentor (AI-M) application developed to foster personalized learning. The application offers features like answering visual questions and providing customized feedback to support students' science learning. The manuscript discusses the development process of this application, its possible implications, and possible improvements. One outcome would be for teachers to develop their application for their students' needs and demands.

Introduction

The role of technology in education is transforming not only the tools but also the teaching processes. The AI-M leads this transformation by providing students with an interactive and innovative platform that supports their learning process. The developed application responds to students' learning needs while enabling teachers to track students' progress and optimize their teaching strategies (Luckin et al., 2016; Damioli et al., 2021).

App Design and Features

Key Components

a. Visual Question Answering: The app allows students to ask visual-based questions on science topics and receive answers in real-time. Artificial intelligence algorithms quickly analyze the questions and produce accurate and comprehensive answers (Fairén et al., 2020).

b. Personalized Feedback: The system provides customized suggestions for individual deficiencies by analyzing their data. This allows students to progress at their own pace and increases their learning motivation (Holicza & Kiss, 2023).

Technical Infrastructure

The artificial intelligence supported virtual science mentor is built on a user-friendly interface, machine learning algorithms, and a cloud-based data management system. This one structure makes it possible to store and analyze student data securely.

Findings

The findings are presented as student success and the role of teachers.

Student Success

According to pilot studies, the success rates of students using the app in science courses increased significantly compared to traditional methods. In particular, visual question answering and immediate feedback features positively affected students' conceptual understanding levels (Donnermann et al., 2022).

The Role of Teachers

The AI-supported virtual science mentor allows teachers to monitor students' progress in detail. This helped them to plan their teaching processes more efficiently (Holicza & Kiss, 2023).

Discussion

The virtual science mentor with artificial intelligence is an innovation that promotes personalized learning experiences in science education. However, challenges such as digital limitations and pedagogical integration of technology may limit the diffusion of such applications. Future studies should develop solutions to overcome these barriers (Luckin et al., 2016).

Conclusion

This study shows that the artificial intelligence supported virtual science mentor application offers an innovative education model and has the potential to help students overcome the difficulties they face in science learning. The application's positive effects on learning processes reveal the potential of artificial intelligence in science education.

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Transdisciplinary Implementation in STEAM Teacher Education

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Keywords: preservice, teacher, preparation, STEAM, transdisciplinary

Abstract

The issue of the interdisciplinary versus transdisciplinary approach to STEAM education is well established in the literature. In this paper I will be presenting our implementation of the transdisciplinary model for STEAM education within the context of our teacher preparation program in Bahrain. The presentation will present our outline of the courses being offered to our cycle 1 pre-service teachers. Next, I will show how we focus on inquiry, design, collaborative learning, and problem solving in our two introductory courses. The presentation will include examples of the resources we use to train our teachers. The implications of this paper are to share our model and receive feedback from the conference participants on the best and most effective methods that are currently being used to teach STEAM in a transdisciplinary way, to prospective pre-service teachers enrolled in international teacher preparation programs.

STEAM education has been identified by UNESCO as an essential component of achieving its sustainable developmental goals in the education realm for the year 2030 (UNESCO, 2017, p.14). STEAM has become important for most countries of the world not only to prepare their students for upcoming jobs in the workplace, but also to instill in them life-long learning skills such as problem solving, critical thinking, and cooperative learning. It goes beyond 21st century skills needed for future jobs, to instilling in students life-long learning skills (Jolly A., 2014, p.3).

Radloff J. and Guzey, S., (2016, p. 759) discussed the intent and need for STEM education to integrate the different subjects. Yet they reported that varied understanding exists amongst pre-service teachers and that there exists a need across all teacher preparation programs to provide effective instruction to pre-service teachers on the integrated nature and meaning of STEM (p.771). The question then becomes how best to integrate the different subjects and how do faculty in teacher preparation programs train their pre-service teachers in the implementation of a STEAM lesson in their classroom. This becomes important as understanding of what STEM or STEAM means differs from one group of professional educators to another. Research has reported the need to have a clear understanding amongst pre-service teachers and teacher educators of the meaning of STEM (Navy S.L., et al., 2021, p.36). Also the question of integrating the different disciplines of STEM education has been argued in the literature a long time ago (English, L.D., 2016, p.1). Of particular concern has been the

under-representation of fields such as math and engineering in STEM lessons. Another argument revolves around the merits of including the art component of STEAM lessons (Fraser S., et al., 2018, p.26). In our presentation we will show how we are able to incorporate the art aspect of STEAM lessons through our design lesson activities.

Vasquez J. (2015) recommends that we strive for STEAM education that utilizes a transdisciplinary approach over the interdisciplinary approach. Transdisciplinarity means that students utilize two or more disciplines of the STEAM integrated subject approach to enrich their learning experience. This advanced approach most often involves project-based learning lesson plans rooted in the constructivist approach to learning.

In this oral presentation we aim to address the issue of transdisciplinarity over interdisciplinarity in our approach to preparing STEAM student-teachers within the Arab context of Bahrain. With our own experience in preparing pre-service teachers in Bahrain we aim to show in this presentation how we have strived to train our teachers in the transdisciplinary approach, offering our own experience as an example.

In our own teacher preparation program, we have planned our introductory STEAM course for pre-service teachers to focus on two aspects of STEAM education: inquiry and design. Our introductory course is organized to include a model STEAM lesson and reflection on the model lesson written by the student teachers. We then ask our students to prepare their own STEAM lesson plans, implement it through a microteaching of their lesson with the end of the semester, and lastly to do a self-reflection on their own teaching as they conclude the semester long course. The students must use a transdisciplinary approach incorporating at least two disciplines in their lesson plans and they must prepare lesson activities that involve both inquiry and design.

Our pre-service teachers are taught to design lessons that are project based or problem based with a constructivist approach to learning. The inquiry part relies on designing an experiment. The lesson involves selecting a problem, forming a hypothesis, involves making observation, gathering data, analysing the data and then arriving at conclusions. The lesson is always conducted through collaborative groups and once the students have reached their conclusions, the results are shared in an end of lesson final class discussion. For the design part students are asked to pick a problem, then design a model, discuss and make improvements to their models, then present their models. The model must address the problem they began with by offering a solution to the problem. Lastly, the students are asked to define the objective of their design (biological, physical, or technological) and they are also asked to link their project to how it might improve people's lives or solve one of society's problems or needs. They are encouraged to link their project to real life applications.

In this presentation we will present examples of how to implement the transdisciplinary approach to STEAM teaching as taught to our pre-service teachers. We will present our list of courses offered for our cycle 1 teachers with a focus on the first two introductory courses. We will show how we implement the transdisciplinary aspect of our STEAM pedagogical training by sharing resources and examples from our pre-ser-

vice teachers. We hope this opens the venue for discussion among fellow experts on the best ways that others have found of implementing this approach to their own pre-service teachers.

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STE(A)M and CITIZENSHIP. Development with processes of inquiry and argumentation in science teacher training and teaching. Identity, environments and gender study (EduCA-STE(A)M)

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Keywords: STE(A)M teacher education; integration programmes; inquiry; argumentation; teacher identity; gender

Abstract

EduCA-STE(A)M is a R+D+I national project to develop teachers' skills in STE(A)M education to train reflective and innovative teachers for the 21st century. Specifically, the general objective is to train competent science teachers for STE(A)M education, addressing sustainable education, the gender perspective and equity, designing, implementing and evaluating microteaching programmes (modules or training pills in different degrees, Bachelor's and Master's), that prepares responsible students in a dynamic world, transferring this vision to citizens through open science events or from educational centres and their projection to society.

Introduction

The project focuses on the STE(A)M approach and citizenship education, promoted through microteaching programmes that consider in-context teaching approaches and the use of scientific practices with preservice and in-service science teachers, as well as to nonformal educational settings. We intend to investigate their implications on the teaching competences developed and learning acquired by students, also the knowledge and attitudes promoted in the public and considering the influence of the professional and gender profile of each group studied.

Theoretical framework

STEM education, driven by political, social, and economic factors, has become a global trend promoting innovation and future readiness. Programmes and resources inside and outside schools have made STEM/STEAM increasingly familiar to teachers, students, and families (Couso, 2020). Effective STEM teaching requires deep content knowledge and specialized pedagogical skills, often using Project-Based Learning (PBL) and scientific practices. However, implementing STEM in classrooms remains challenging and demands better teacher preparation. Despite its emphasis on problem-solving, real-world contextualization, and interdisciplinarity, few studies have analysed the promotion of integrated STEAM projects (McLure et al., 2022). These complexities high-

light the need for improved strategies to transfer STEM/STEAM effectively into classrooms (Margot and Kettler, 2019).

Teaching within environments that incorporate the STEM perspective (Martín-Páez et al., 2019) serves as a key foundation for developing critical skills in students (Couso & Simarro, 2020). This approach goes beyond merely transferring information, aiming instead to cultivate critical thinking and problem-solving abilities. It integrates the content and processes of scientific practices, empowering students to formulate questions, conduct investigations, and build arguments—essential skills for shaping reflective citizens and educators. However, there are challenges in designing educational programs from this perspective. Integrated STE(A)M teacher training programs are necessary to foster teaching models that provide meaningful learning experiences and skills development. Among the variety of teaching methods, context-based teaching is a particularly effective approach, as shown in educational research. Choosing a relevant context or analysing everyday life situations is not just a backdrop for learning; it is a vital part of the process.

Using scientific processes like inquiry and argumentation enhances the relevance of science in understanding both natural phenomena and everyday situations. It promotes students' STEM competencies, critical thinking and boosts their academic performance, contributed to school-based citizen science (Evagorou et al., 2023) will enable students to make informed, responsible decisions, sustainable consumption, healthy habits, energy use, and environmental conservation and emphasizing the importance of gender perspectives. Understanding identity and gender dynamics is crucial for designing inclusive strategies that address disparities and ensure equitable access to science education for all. Also, recognizing that STE(A)M education extends beyond the classroom, and it fosters stronger connections between formal education and society, creating a vital foundation for civic education.

Methods

The project aims to design and implement micro-training programmes (Figure 1), through three phases with the participation of several roles of teachers (preservice or in-service): 1) Science Learners; 2) Teacher's learners; 3) Designers.

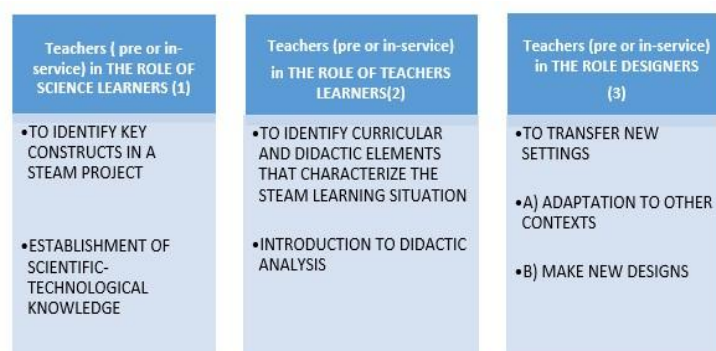


Figure 1. Planification of the STE(A)M micro training programmes

We have considered several innovative elements to build the lesson studies like learning situations used in the training programmes:

- Integration of STEM: It adopts a holistic STE(A)M approach that emphasizes critical thinking, problem-solving, and scientific inquiry, benefiting both students and educators.
- Context-Based Learning: Real-life situations are central to the learning process, helping students apply knowledge in meaningful ways.
- Scientific Inquiry and Argumentation: The use of inquiry and argumentation processes enhances the relevance of science, fostering STEM competencies and critical thinking.
- Civic Education: The concept of "citizen science" encourages responsible decision-making on issues like sustainability and health.
- Sustainability and Equity: The proposal emphasizes sustainability and equity, preparing students to address global challenges ethically.
- Gender Perspectives: It incorporates gender considerations to ensure inclusive, equitable science education.
- Collaboration Beyond the Classroom: Partnerships with civil institutions expand the impact of STE(A)M education, strengthening the link between formal education and society.

Results

To design and implement our STE(A)M integrated learning situation, we have recognized a model with the participation of key constructs from three focus (Figure 2): *STE(A)M itself nature*; *Scientific practices approaches* selected for teaching (argumentation and inquiry processes), and *Classroom learning situations* through various educational stages (Girón & Lupión, 2025).

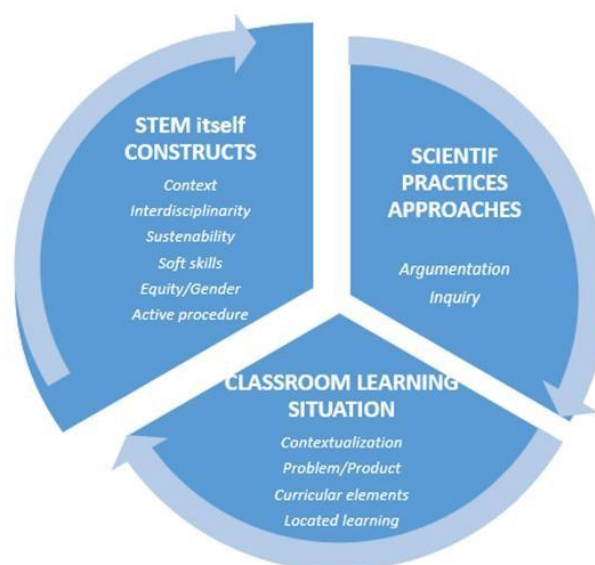


Figure 2. Model of key constructs in the integrated learning situation of the EduCA-STE(A)M project

Among the different teaching methods aligned with the STEAM approach, context-based teaching stands out as particularly effective. Selecting or analyzing real-life situations is not merely a background element for learning; rather, it plays a central role in motivating students.

Regarding specific pedagogical approaches, inquiry-based learning is considered especially relevant for fostering student motivation, as it promotes the development of broad skills such as decision-making, reasoning, problem-solving, argumentation, and investigation (Vázquez-Alonso & Manassero-Mas, 2018). In designing classroom learning experiences, project-based learning (PBL) offers opportunities for students to develop STEM competencies by engaging in meaningful activities. These activities allow learners to identify and apply foundational knowledge, as well as the modes of thinking, reasoning, communicating, and feeling characteristic of science, engineering, and mathematics (Pérez-Torres et al., 2021). Such environments enable students to exercise intentional self-regulated judgment, resulting in subjective interpretations (Facione, 1998).

From these factors, we are analyzing the impact on teachers' teaching abilities and the shaping of their professional identity with diverse learning situations at different educational levels, focusing on citizen-oriented topics such as sustainable city management (Girón & Lupión, 2025), climate pollution, and the use of green spaces.

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What makes a STEAM teacher? Modelling interdisciplinarity for future teachers

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Keywords: STEAM education, interdisciplinary education, teacher training

Abstract

21st-century challenges demand interdisciplinary responses; accordingly, STEAM education is an appropriate framework for preparing preservice teachers in interdisciplinary work. This case study examines how collaboration among university educators, organized as a Community of Practice (CoP), contributed to teacher training through four STEAM projects. The CoP members encountered multiple challenges and tensions in their collaborative work, which they addressed by developing strategies that sustained both the design and implementation processes. During the implementation of the projects, teacher educators employed diverse formative practices that modeled interdisciplinary education in pre-service teachers.

Introduction

The challenges of the 21st century demand a paradigm shift in education, and STEAM has emerged as a promising approach to foster problem-solving skills (Quigley et al., 2017). Preparing future teachers to design and implement integrated instruction is therefore crucial to address these challenges (Berisha & Vula, 2024). This requires that pre-service teachers experience integration supported by teacher educators (Correia & Baptista, 2022). The integrated nature of STEAM also demands collaboration among educators from diverse disciplines (Weinberg et al., 2021). Although research on STEAM preservice teacher education remains limited, recent advances appear in Spyropoulou and Kameas (2024), who show of how teacher educators' model interdisciplinarity in preservice programs working within a CoP. This study explores how collaboration among university educators, organized as a CoP, models interdisciplinary design in STEAM education and supports preservice teachers in developing the capacity to plan and enact integrated learning activities.

Framework

STEAM education is an approach that integrates Science, Technology, Engineering, Arts, and Mathematics through common skills, content, and practices (Perignat & KatzBuonincontro, 2019). A common feature across frameworks is disciplinary integration via real-world problems (Quigley et al., 2017), although research varies in the number of disciplines included and their roles (Moore et al., 2020). Regarding the A, Aguilera and Vílchez-González (2024) point out that STEAM projects integrate it as hu-

manities, arts, aesthetics, and creativity. Disciplinary integration can be conceptualized as a continuum of learning approaches: multidisciplinary, where disciplines remain separate but share a common context (English, 2016), each pursuing its own learning objectives, with no coordination in activity design (Silvestri et al., 2025); interdisciplinary, where closely linked concepts and competencies are learned together to deepen understanding (English, 2016); and transdisciplinary, where boundaries blur (Quigley et al., 2017) and concepts and competencies are jointly applied to real-world problems (Silvestri et al., 2025), fostering new ways of thinking in problem-solving (English, 2023).

To achieve high levels of disciplinary integration and effectively teach 21st-century skills (Beswick & Fraser, 2019), pre-service teachers need to develop both content knowledge (CK) and pedagogical content knowledge (PCK) (Correia & Baptista, 2022). Lesson planning is a relevant strategy for bridging theory and practice in STEAM (Bergsten & Fredj, 2019). However, many pre-service teachers lack experience in STEAM education, particularly in using different knowledge domains interdependently (Rodrigues-Silva & Alsina, 2022). Training pre-service teachers in STEAM education requires teacher educators to collaboratively design and implement training tasks. The design phase entails tensions: balancing deep scientific ideas with social impact; integrating subjects while maintaining disciplinary depth; selecting contexts that are both relevant to students and scientifically meaningful; and fostering key competencies while obtaining clear evidence of learning (Pérez-Torres et al., 2021). Additional challenges include understanding the nature of disciplinary integration while working with real-world contexts (Berisha & Vula, 2024), limited time and resources and experience in interdisciplinary education (Park et al., 2016); and difficulty collaborating with colleagues, which may stem from differences in disciplinary cultures and approaches (Spyropoulou & Kameas, 2024).

One response to these challenges is to organize pre-service teacher training within communities of practice (CoP) (Spyropoulou & Kameas, 2024), collectives structured around mutual engagement, a joint enterprise, and a shared repertoire (Wenger, 1998). CoP can foster the creation of integrated learning environments to promote interdisciplinary connections (Weinberg et al., 2021). As well, they can alleviate disciplinary barriers through mutual support and shared expertise (Jho et al., 2016). Regular interaction enables CoP members to improve their practice individually and collectively (Spyropoulou & Kameas, 2024) through collaboration with experts from different disciplines (Boice et al., 2024). Such interdisciplinary collaboration is fundamental to help pre-service teachers grasp the interconnections and practical applications of integrated subjects (Berisha & Vula, 2024).

Methodology and context

Conducted at Universidad Complutense de Madrid, this case study analyses the work of 12 university educators from the Department of Didactics of Social and Experimental Sciences and Mathematics. These educators collaborated as a CoP within a teaching innovation initiative (PIMCD420), with the aim of designing STEAM-based

tasks for the initial training of Early Childhood and Primary Education teachers. The group sought to promote integrated learning across their disciplines, sharing a common interest in STEAM education. They engaged in debates around the role of the A in STEAM, connected organically with the humanities. As a starting point, they drew on the previous work and experience of Dr. Belén Palop in STEAM teacher training (López-Luengo & Palop, 2024) to collaboratively develop four projects (Table 1) during the 2023/24 academic year. Educators explored two teaching approaches: (a) shared subjects and (b) shared tasks within separate subject blocks taught by disciplinary specialists. Within this framework, pre-service teachers were positioned either as solvers of interdisciplinary challenges or as designers of interdisciplinary tasks.

Table 1

Projects designed and implemented

ID	Disciplines	Instruction	Focus	Students' objective
P1	Mathematics Experimental sciences	Shared subject	CK	Design a multifunctional classroom using scaled plans and research on thermal and acoustic insulation
P2	Mathematics Social & Experimental sciences	Shared subject	CK PCK	Design interdisciplinary activities on change and permanence in the context of a Royal Garden
P3	Mathematics Social sciences	Separate subjects	CK PCK	Design activities contextualized in a Roman market integrating history and mathematics
P4	Mathematics Social sciences	Separate subjects	PCK	Design learning materials linking social sciences and mathematics through museum artefacts

Data were collected to capture both the process of collaboration, and the products generated by the CoP. Participant observation was carried out during co-design sessions and classroom implementations. Project documents and resources from the four projects were gathered. In addition, semi-structured interviews were conducted with one teacher educator per project to collect their reflections on collaborative design and interdisciplinary teaching. An inductive thematic analysis was conducted, searching for topics and patterns related to two main categories: (1) challenges and barriers encountered by teacher educators, and (2) working strategies developed to overcome barriers. A third category emerged, on practices to enhance pre-service teachers interdisciplinary CK and PCK. Additionally, we used the tool developed by Boice et al. (2024) to analyze the degree of integration in our projects, positioning them along the contin-

uum according to interdependence of tasks, promotion of connections, and modes of co-teaching.

Results

The four projects varied in their level of disciplinary integration, ranging from multidisciplinary to interdisciplinary. At the multidisciplinary level, P1 showed low interdependence and limited connections between disciplinary concepts and tasks, although there were some moments of shared instruction. In P4 the tasks from each discipline were complementary rather than essential; some connections were promoted, but instruction remained separate. P3 showed a higher level, with tasks partially interdependent and strong connections promoted between disciplinary concepts, but with teachers instructing separately within their disciplines. Finally, P2 achieved interdisciplinary integration, with strong interdependence between tasks, explicit promotion of connections, and co-teaching sessions.

Analysis reveals four main challenges and barriers faced by teacher educators in the design and implementation of the projects. First, a lack of experience in interdisciplinary education was evident in the difficulty of understanding the didactics and concepts of other subjects (P3) and in the limited experience in designing interdisciplinary projects (P2, P4). Secondly, unrecognized workload and limited time due to unrecognized teaching of some educators (P1), the excess responsibility assumed by the team leader (P2), scheduling problems (P3), fragmented implementation (P4), and the imbalance between time available and disciplinary depth (P1). A third challenge concerned the balance in the integration of disciplines, reflected in the risk of mathematics being relegated to an instrumental role (P3), the lack of relevant contexts for learning mathematics (P3), and weak connections between disciplines (P1). There was a tension between maintaining rigor and depth in each discipline and achieving interdisciplinarity (P1, P2). Finally, there were difficulties in evaluating products and processes in P1.

To address these challenges, the members of the CoP developed a range of working strategies that enabled them to collaboratively design and implement the projects while sustaining interdisciplinary integration. All teacher educators involved in the four projects engaged in collaborative co-design and joint planning of activities. In doing so, some teams searched for contexts with strong potential for disciplinary integration, such as change and permanence (P2) or measurement (P3). Co-teaching took place through multiple educators present in all sessions (P1) or through shared teaching sessions (P2). These processes of collaboration required continuous communication: through regular meetings in the projects with shared instruction (P1 and P2) and occasional meetings in those with separate instruction (P3 and P4). Communication was reinforced by mutual trust in the expertise of CoP members, both in the CK and the PCK specific to each discipline.

Finally, teacher educators employed diverse formative practices that helped pre-service teachers develop interdisciplinary CK and PCK. The first was the provision of

models and guidance, including templates with project requirements (P1, P4), continuous accompaniment during sessions (P1, P2), and the didactic advice offered by in-service teachers (P2). A second practice, theory-to-practice scaffolding, involved moving from theory into the design of activities (P2, P3). A third, didactic restrictions and coherence, included criteria to maintain disciplinary rigor (P2) and specific restrictions to guide task design (P3). Finally, live demonstrations of collaborative teaching appeared in P1, P2, and in one lesson of P4. This approach, enacted through the joint presence of several educators during sessions, worked as a model for pre-service teachers, showing collaboration, shared expertise, and the building of interdisciplinary education during project implementation.

Final thoughts

This study examined how a CoP of university teacher educators can model interdisciplinarity for pre-service teachers through STEAM education. In the process of designing and implementing the projects, the CoP faced several challenges that have already been found in previous research. Teacher educators struggled due to limited experience in STEAM, faced time and workload constraints (Park et al., 2016), encountered difficulties in achieving balanced disciplinary integration, and confronted the tension between pursuing high levels of integration while maintaining disciplinary rigor (Pérez-Torres et al., 2021). To address these challenges, CoP members developed several working strategies: collaborative co-design, selection of integrative contexts, co-teaching, continuous communication, and mutual trust. These learning experiences supported preservice teachers in developing both CK and PCK (Correia & Baptista, 2022) and, as observed, modeled collaborative practices essential for integrated teaching. These findings align with previous research showing that CoPs can mitigate disciplinary barriers while serving as professional learning environments for educators and as pedagogical models for pre-service teachers in STEAM education (Spyropoulou & Kameas, 2024; Weinberg et al., 2021). Beyond their shared focus on STEAM education, the CoP refined activities that were re-implemented in later courses and collectively contributed to the creation of the master's program *Research and Innovation in the Teaching and Learning of Experimental, Social, and Mathematical Sciences*, embedded within STEAM education. This outcome illustrates how the mutual engagement and shared repertoire of the CoP extended the impact of the four projects into a sustainable framework for teacher education. Future research should explore more effective ways to assess integrated learning. In addition, there is a need to strengthen how future teachers learn to design interdisciplinary tasks and projects.

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Fostering Teacher Collaboration Across Europe: Insights, Challenges, and Future Directions

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Introduction

Teachers' Collaboration can take many forms, from co-teaching and co-designing lessons within the same classroom or school to more extensive regional, national, or international partnerships. Based on the aims of an established expert group of ICSE (International Consortium of STEM Education), this paper reports on findings from an ETE V 2025 conference workshop investigating the landscape of teacher collaboration across several European countries. Relating to various theoretical frameworks, the workshop aimed to identify the contexts, conditions, participants, and practices shaping collaborative efforts within STEM education. The paper builds on existing research (e.g., ICMI Study 25), highlighting the benefits of teacher collaboration for pedagogical innovation and the creation of professional learning communities.

Theoretical underpinnings

Teacher collaboration has become a significant focus of research in teacher education over the past two decades. This area has been explored across various STEM subjects. In mathematics education, for instance, numerous studies on mathematics teacher collaboration have been published in journals, conference proceedings, and handbooks (e.g., Jaworski et al., 2017). Currently, ICMI Study 25 presents the state of the art in this field (Borko & Potari, 2024), identifying four key dimensions: theoretical perspectives; contexts, forms, and outcomes of collaboration; resources for and from teacher collaboration; and participants (including roles, identities, and interactions) in teacher collaboration. Esteley et al. (2024), building on the previous work of Esteley (2014), report that mathematics teacher collaboration occurs at multiple levels (e.g., at the national, institutional, and classroom levels). The goals of such collaboration include promoting changes in teachers' knowledge and practices, designing curriculum resources, and developing professional communities. Forms of collaboration vary, including both face-to-face and blended formats. The outcomes range from professional learning for teachers and educators to producing teaching resources and even to unexpected results. Karsenty et al. (2024) consider a broad range of participants involved

in teacher collaboration groups. These include supporters such as mathematics teacher educators, facilitators, mentors, knowledgeable others, leaders, pedagogical instructors, multipliers, and other stakeholders such as policymakers and teachers from different disciplines. Their findings highlight the crucial role of facilitators in promoting mathematics teacher collaboration, the strategies used to prepare and educate facilitators, and the significant influence of the surrounding environment. While most studies focus on collaboration among mathematics teachers, a few address interdisciplinary collaboration. For example, in the Bakogianni et al. (2021) study, the teacher educator supporting collaboration between science and mathematics teachers encountered challenges related to epistemological differences between the two disciplines and existing norms in mathematics and science teaching.

The organisation of the Workshop

These theoretical perspectives informed the workshop's design and content, where researchers from six countries (Belgium, the Czech Republic, Germany, the Netherlands, Portugal, and Slovakia) with various STEM backgrounds participated. Two groups were formed and asked to discuss (a) the contexts and conditions (C&C) of teacher collaboration, and (b) the practices and participants (P&P) in teacher collaboration.

Results and Emerging Issues: Context and Conditions

Across the surveyed European countries, teacher collaboration exists predominantly within individual institutions rather than systematically across schools or national levels. Institutional contexts commonly provide structured opportunities such as departmental meetings or mandated subject-group planning sessions, observable in countries like Germany, Slovakia, and the Netherlands. However, these collaborative opportunities often remain underutilised due to workload pressures and resource constraints. Teachers frequently limit collaboration to curriculum alignment, shared lesson planning, or joint assessment design, rather than deeper pedagogical innovation or interdisciplinary integration.

Specific localised initiatives have emerged to stimulate teacher collaboration at the institutional level. For instance, some Slovak schools have attempted to establish teacher clubs focused on co-designing instructional materials. Despite the potential of these clubs, outcomes have been inconsistent, primarily due to a lack of external facilitation—an absence of "knowledgeable other," whose presence is critical for sustaining collaboration, guiding innovation, and bridging gaps across departmental boundaries. Thus, sustainability and longitudinal impact remain questionable without robust institutional or external support.

National and regional educational policies also significantly shape the context of teacher collaboration. Despite team-teaching opportunities in national curricula (e.g., in the Czech Republic), systemic factors such as inadequate funding and teacher shortages inhibit widespread implementation across European countries. Thus, collabora-

tive practices tend to be sporadic rather than systematic, largely dependent on individual educators' motivation and initiative. This inconsistency represents a significant missed opportunity for broader educational innovation and knowledge sharing at national and transnational scales.

However, regional educational systems or international school networks (e.g., International Baccalaureate—IB) demonstrate greater potential for systematic collaboration, though they still face limitations. For example, IB schools explicitly encourage collaboration within the school; yet, trans-school or international networking among teachers remains informal and relies mainly on individual efforts rather than institutionalised processes. This leads to isolated pockets of excellence that rarely transfer across institutional boundaries.

A compelling exception within the European context is Portugal's Academi@STEM Mangualde collaboration initiative, representing a structured approach to inter-school collaboration. This innovative project gathers teams of teachers from different schools and disciplines. To collaboratively co-design STEM teaching materials. Participating teachers receive reduced teaching loads, the assistance of facilitators and technical experts, and specialised resources. Here, Esteley's (2024) concepts of "brokerage" and "boundary crossing" become particularly evident. Each participating teacher acts as a broker, bringing their disciplinary expertise, school-specific pedagogical cultures, and classroom experiences into the co-design process. Consequently, these educators effectively transfer new knowledge and innovative practices to their home schools, creating a dynamic cross-pollination of ideas and practices that transcends institutional boundaries.

In contrast, such boundary crossing remains absent mainly in Slovakia and similar contexts, where collaboration is typically limited to internal institutional arrangements without structured external support. The absence of brokers-educators or facilitators explicitly tasked with bridging institutional boundaries-significantly restricts opportunities for sustainable educational innovation and interdisciplinary synergy.

Results and Emerging Issues: Practices and Participants

Collaboration at the classroom level frequently involves pre-teaching, co-creation, and consultation on lesson content. This process includes joint planning of learning objectives, sharing teaching strategies, and designing common assessments. Tandem teaching—where two educators collaboratively manage classroom instruction—takes on multiple forms: rotational, parallel, and supportive teaching. In Germany, tandem teaching may occur twice a week in some schools, allowing for greater differentiation and personalised student support. There has been a noticeable increase in tandem teaching in the Czech Republic, particularly in response to post-pandemic needs for individualised learning support and socio-emotional development. However, budgetary issues often constrain implementation, particularly regarding additional staff funding. Belgium applies co-teaching predominantly in language instruction, fostering peer learning and linguistic immersion. The approach is relatively rare in Portugal, while

Norway's traditional one-teacher model persists. Norwegian classrooms benefit from structured collaboration with teaching assistants and special education professionals, enhancing inclusive education. Across all countries, subject-specific committees and teacher learning communities contribute to the professional dialogue around instructional improvement.

At the school level, leadership is critical in cultivating a collaborative culture. The principal's support is essential for creating time and space for collaboration, encouraging interdisciplinary projects, and fostering mutual trust among staff. In Portugal, regular two-hour STEM teacher meetings provide opportunities to review student performance data, align curriculum, and pilot innovative teaching approaches. The Czech Republic supports collaboration through subject committees that may span related disciplines, fostering a more holistic approach to education. These include interdisciplinary groups such as "Man and Nature" and "Mathematics and its Applications". Belgium emphasises team teaching and pedagogical coherence across grade levels. Norway facilitates collaboration through regular departmental meetings and structured reflection sessions that help identify best practices and address common challenges. Germany formalises collaboration by appointing deputy principals responsible for specific subject clusters (e.g., STEM), who facilitate teacher cooperation and professional development.

At the national level, institutional support for teacher collaboration varies but generally includes teacher training institutions, professional associations, and ministry-led initiatives. Portugal's Teacher Training Centres offer many professional development courses encouraging peer interaction and collective inquiry. Teacher-training centres provide mentoring, consultation, and networking opportunities for teachers across the Czech Republic and Slovakia regions. Germany supports subject-based collaboration through professional associations, which organise conferences, publish research, and offer collaborative forums. Norway promotes digital platforms and national professional learning networks, enabling teachers to connect across schools and regions. Universities in all participating countries play a foundational role in pre-service and in-service training, with many institutions developing partnerships with schools to facilitate action research, mentoring, and reflective practice.

International collaboration is increasingly recognised as a powerful driver of innovation in education. Participants highly valued their engagement in international initiatives, particularly those led by the International Centre for STEM Education (ICSE). Programmes such as the ICSE Teachers Academy enable educators from different countries to co-design instructional materials, engage in shared professional learning, and explore diverse perspectives on teaching and learning. The Erasmus+ programme is a cornerstone of international cooperation, offering mobility opportunities, joint projects, and strategic partnerships that enrich the educational experiences of both teachers and students. Such international engagement enhances professional development and fosters a sense of global citizenship and solidarity among educators.

Summary of Workshop Results

Analysis of the C&C group's outcomes showed that while institutional contexts frequently provide basic collaborative opportunities – such as departmental meetings – systemic barriers like workload, funding, and teacher shortages impede widespread, effective practice. The Portuguese “Academi@ STEM Mangualde” initiative emerged as a compelling example of successful collaboration, showcasing the importance of dedicated external support, “boundary brokers,” and intentional policy frameworks. The consistent need for facilitators was highlighted as crucial for sustainability and innovation.

The P&P group's discussion illustrated collaboration across multiple levels: classroom, school, national, and international. While classroom collaboration focused on co-teaching and shared planning, school-level success depended heavily on strong leadership and dedicated time for collaboration. National support varied significantly, with Portugal's Teacher Training Centres and Germany's subject-based associations playing key roles. International initiatives, particularly those facilitated by ICSE and Erasmus+, were highly valued for their potential to enhance professional development and promote global perspectives.

Implications

The workshop results reinforce the need for continued, nuanced research into the multifaceted nature of teacher collaboration. Existing literature, while substantial, often lacks granular detail regarding the contextual factors influencing collaboration's success. Future research should prioritise longitudinal studies investigating the impact of specific collaborative models on student outcomes, moving beyond self-reported teacher perceptions.

The workshop results offer practical guidance for educators and school leaders in fostering collaborative environments. Collaboration cannot be an add-on; it requires dedicated time and financial resources. Principals and other school leaders must actively champion collaboration, creating a culture that values shared knowledge and collective problem-solving.

The workshop findings underscore the need for policy changes at national and regional levels to support teacher collaboration. National education ministries should invest in training programs for teacher facilitators, equipping them with the skills and resources necessary to support effective collaboration. Dedicated funding should be allocated to support collaborative projects, including inter-school networks, curriculum development, and professional development opportunities. Supporting international exchange programs and collaborative initiatives, encouraging educators to learn from best practices across Europe and beyond, is a promising strategy.

Going Beyond the Workshop: Broader Perspectives and Visions for STEM Teacher Collaboration in Europe

The growing emphasis on teacher collaboration globally reflects a broader shift in educational thinking. Moving away from the traditionally isolated “lone teacher”

model, contemporary pedagogy increasingly prioritises collective expertise and shared responsibility for student learning (Borko & Potari, 2024). This shift is driven by several factors, including increasing complexity in the curriculum, the need to address diverse student needs, and the recognition that teachers learn from and with one another (Esteley et al., 2024). The workshop participants' experiences, aligned with findings from ICMI Study 25, demonstrate that collaboration is not a monolithic practice. It exists across multiple levels – from classroom coteaching to national policy initiatives – and manifests in diverse forms. However, successful models are not solely defined by investment. The deliberate inclusion of “brokers” – facilitators who bridge institutional boundaries and foster knowledge transfer – proved critical. This echoes research emphasising the importance of social capital and network structures within teacher communities (Karsenty et al., 2024). Future initiatives must prioritise joint professional development that addresses these challenges, fostering mutual understanding and shared pedagogical strategies. In sum, fostering effective STEM teacher collaboration requires a systemic approach. It demands a coordinated effort involving policymakers, school leaders, teacher educators, and teachers to create a more dynamic educational landscape for all learners.

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Development of a Sustainable PBL Curriculum for Junior High School Science: Recovering Traditional Salt Production Activities After Large-Scale Natural Disaster

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Keywords: PBL, Science Teaching, Traditional Salt Production, Large-Scale Natural Disaster

Abstract

We developed a Project-Based Learning (PBL) approach that addresses meaningful societal issues such as disaster recovery. The Noto region in Japan has practiced a unique method of salt production using seawater since 1596. In 2024, a magnitude 7.0 earthquake struck the Noto Peninsula, followed by record-breaking rainfall, which caused devastating damage to salt production facilities located between the coastal and mountainous areas. This PBL unit focuses on salt production from seawater as a context for teaching scientific concepts. It not only makes science more relevant and engaging for students but also encourages critical thinking. Furthermore, it demonstrates how PBL can be an effective tool for fostering a more sustainable society and preserving cultural heritage.

Introduction

The Noto region in Japan has preserved a distinctive method of salt production using seawater since 1596, a tradition that continues today (Discover Ishikawa Japan, 2024). The process involves: (1) spreading seawater on salt fields, (2) collecting the sand sprinkled with seawater, (3) filtering and collecting the liquid with a salinity of 20 degrees, (4) performing rough boiling until salinity reaches 24 degrees, and (5) slowly boiling for about 12 hours to evaporate the water and remove the bittern (a concentrated liquid byproduct) (see Picture 1). The salt produced is not only consumed as food but also serves as an essential ingredient in tofu production, both domestically and internationally.



Figure 1. Main Procedure of Traditional Salt Production at "Agehama Salt Field"

However, on January 1, 2024, a magnitude 7.0 earthquake struck the Noto Peninsula. This was followed by record-breaking rainfall on October 21, which severely damaged salt production facilities located in coastal–mountain transition zones.

Research Question and Theoretical Framework

Developing PBL with Real-World Relevance and Social Practice

One of the major challenges in Japanese science education is students' low attitudes toward science. According to OECD (2023), Japanese students score in PISA 2022 below the OECD average on all indices: enjoyment of science, participation in science activities, motivation to learn science, and self-efficacy. A possible explanation is that science content often appears fragmented and insufficiently connected to reality or social practices.

Therefore, it is a significant challenge to design a PBL unit that situates prescribed scientific concepts within an authentic practice such as salt production. This study explores the elaboration of a PBL approach in junior high school science to foster students' engagement with real-world and socially pressing issues.

We formulated the following research questions:

- How can a PBL approach be designed to cover prescribed topics while situating them in a socially relevant practice such as “salt production from seawater”?
- To what extent can this PBL approach make science more relevant and engaging for students?

IQWST: A Model Framework for PBL in Science Education

PBL provides opportunities for students to engage in authentic scientific practices and problem-solving through hands-on projects connected to real-world issues. However, PBL remains underdeveloped in Japan. To support our design, we adopted the NSF-funded theoretical framework “IQWST” (Investigating and Questioning Our World through Science and Technology), developed by Krajcik and Shin (2022).

The IQWST framework emphasizes connecting scientific concepts to realistic, socially relevant problems, thereby fostering authentic understanding. Its key characteristics include:

- Driving Questions
- Clear Learning Objectives
- Participation in Scientific Practices
- Collaboration
- Use of Technology (ICT support)
- Creation of Artifacts (final products)

Methodology

Japanese Lesson Study Approach to IQWST-PBL

Japanese Lesson Study (Fujii, 2015) is a widely practiced model of school-based professional development that involves three processes: collaborative task design for a Research Lesson (RL), implementation of the RL with participant observers, and post-lesson reflection with all participants.

In this study, an in-service teacher (Mr. Takeda), science teacher from a public school, and the author collaboratively designed a PBL unit, with special attention to IQWST Chemistry curriculum (Krajcik, J. S., Reiser, B. J., Sutherland, M. L., & Fortus, D., 2021).

Four Key Characteristics of IQWST Applied in Lesson Study

Topic Consistency: The project was designed around the junior high school first-year science unit "Properties of Aqueous Solutions" and integrated the real-world context. This approach connects the scientific concepts of dissolution, concentration, and separation of substances to the practical process of extracting salt from seawater.

Driving Question: The unit was based on the first-year junior high school science topic "Properties of Aqueous Solutions" and integrated the real-world context of salt extraction. Students explored dissolution, concentration, and separation of substances through the lens of salt production. The central inquiry was: "*How can we extract useful substances from a solution?*" (e.g., "*How can salt be made from seawater?*").

Scientific Practices: Students carried out experiments to extract salt from seawater, investigating physical properties such as solubility and concentration. The lessons were designed to integrate real-world problem-solving with scientific concepts, allowing students to explore authentic questions.

Driving Questions Board (DQB): Reflection sheets are filled in every lesson. Students' the beginning of each lesson. By posting their questions on the driving question board, questions were collected, categorized, and displayed on the DQB, which was reviewed at students were seen trying to answer the questions of other students. This process nurtured curiosity and provided continuity across the unit.

Results

Consistent among Topics

The PBL unit (Takeda, 2024) was designed around seven lessons in the "Properties of Aqueous Solutions" unit (Oya et al., 2021). Table 1 outlines how National Science Standards were aligned with lesson topics and PBL questions.

Table 1
Elaborated Unit Design

Lesson	Topic	National Standard	Question in PBL
Day 1	Dissolution substances	of Dissolution of copper sulfate in water. The copper sulfate gradually spreads into the water.	Salt dissolves in seawater. What does it mean to dissolve?
Day 2	Concentration	Compare copper sulfate solutions of different concentrations and think about which one is more concentrated.	How much salt can be produced from seawater?
Day 3	Solubility	The amount of a substance that dissolves in a certain amount of water varies	How much salt can dissolve in seawater?
Day 4	Extraction of substances	depending on the type of substance and temperature. Compared to the potassium nitrate, amount of sodium chloride dissolved in water does not change much depending on the temperature.	Why do we evaporate seawater to make salt?
Day 5	Extraction of substances	Compared to the potassium nitrate, amount of sodium chloride dissolved in water does not change much depending on the temperature.	What is the solid substance when seawater is evaporated? Why do we separate bittern when making salt?
Day 6: RL	Extraction of pure substance	Extraction only alum from an aqueous solution of alum and a small amount of copper sulfate.	What happens if seawater is further evaporated after removing the bittern?
Day 7: RL	Making salt from sea water	None	

Driving Question

The Driving Question of the unit was: *“How can we extract useful substances from a solution?”* In other words, “How can salt be made from seawater?” On Day 1, students watched a video about traditional salt making at the “Agehama Salt Field” (Discover Ishikawa Japan, 2024) as the anchor event.

Scientific Practices

We focus on RLs on Day 6 and 7. In Day 6, students evaporated seawater to create concentrated brine. A white solid appeared, which they filtered and observed under a microscope. The rod-shaped crystals led some students to conclude that the solid was not sodium chloride. Some correctly identified it as calcium sulfate (*Photos 2*).

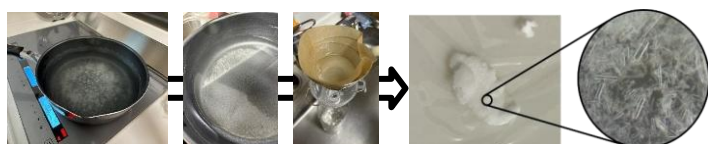


Figure 2. Main Procedure of Experiment in Day 6

On Day 7, students continue evaporating the concentrated seawater. As the water evaporates, the solids that has not completely dissolved come out. Separate the solids from the bittern (filtrate) and observe the solid under a microscope (*Photos 3*). Students recognized the octahedral salt crystals under a microscope and raised shouts of joy.

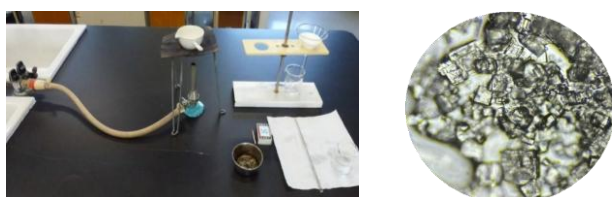


Figure 3. Equipment used in Experiment and Solid observed under a Microscope

Reflection Sheets & DQ Board

Students completed reflection sheets after every lesson. New questions were added based on what students had learned during each lesson. Their questions were added to the DQB (*Photo 4*), which captured diverse interests and curiosities. Their questions were categorized (salt production itself, dissolution itself, dissolution of substances, concentration, calculation method for concentration, melting capacity limit, how to extract the solute, and so on) and added to the DQB, which captured diverse interests and curiosities. Examples included:

- “Does the concentration and taste of salt remain the same?”
- “What other substances are found in seawater?”
- “What does ‘pure’ mean?”

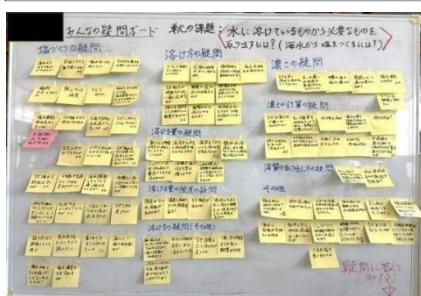
【今日の学び】

・分かったこと、考えたこと、大切に思ったこと、気になったことは？

What did you understood, thought about, found important, and caught your attention?

・疑問に思ったこと、調べてみたいことは？

Things curious about and want to find out



Today's Learning】

Figure 4. Reflection Sheet and Accumulated DQB by Day 6

After the unit, students submitted Final Reports (Figure 5).

疑問に思ったこと :
Questions I had.
疑問に対して自分なりに調べたり考えたりしたこと :
What you have investigated or thought about the question.
Methods: Textbook, Other resources,
Internet, and Otherwise ().
調べた方法:【教科書・教科書以外の本・インターネット・その他()】

Figure 5. Final Report Template

Some questions in the Final Repots include:

- What about sugar instead of salt?
- Why can all substances in seawater be extracted in almost the same way?
- Do all aqueous solutions have crystals?
- Can't you extract the crystals by cooling it?
- Can you extract just the water from seawater using the same materials you normally use?
- Is the extraction method the same for solutions other than aqueous solutions?
- Why does the crystals have such shape?

Discussion

Through this PBL approach, students not only learned key scientific concepts but also engaged in problem-solving related to the authentic challenge of extracting salt from seawater. Their inquiries were integrated into the lessons, sustaining engagement and encouraging critical thinking.

Importantly, a central student question—“*Why do we need to remove bittern (nigari) during salt production?*”—was directly linked to scientific concepts addressed later in the unit, such as solubility curves and separation of mixtures.

This suggests that PBL, when grounded in authentic cultural practices and societal challenges, can be an effective pedagogical tool. It supports sustainable science education while also contributing to the preservation of cultural heritage.

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Understanding the One Health approach through animation videos

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Keywords: One Health, video, antibiotic resistance, climate change, STEM

Abstract

This study highlights the importance of interdisciplinary STEM education in addressing realworld challenges through the One Health concept, which links human, animal, and environmental health. One Health has emerged as a collaborative response to complex health issues that individual disciplines cannot solve alone, gaining prominence during global crises such as H5N1 and COVID-19. Formalized in the 21st century by organizations like WHO and FAO, the approach emphasizes problem-solving, communication, and teamwork-skills that STEM education is uniquely positioned to develop. Despite its potential, interdisciplinary STEM education faces challenges, including limited teacher training, traditional curricula, and scarce resources that connect STEM domains. To address these gaps, this study sought to enhance understanding of One Health through multimedia learning materials. Two videos were produced: one on antibiotic resistance and another on the impact of diet on climate change. These resources were tested with 150 university students, who subsequently designed educational activities for secondary school students, reaching approximately 900 learners. Multimedia played a central role in this process. By presenting information through visual and verbal channels, it fostered deeper integration of knowledge across disciplines. Research shows that multimedia enhances engagement, motivation, and accessibility, offering multiple pathways for students with diverse needs. However, its effectiveness depends on thoughtful design to prevent cognitive overload and fragmentation. Teachers, therefore, are key to aligning multimedia resources with interdisciplinary goals and guiding students in navigating complex concepts. To ensure accessibility and dissemination the videos were made available on a WordPress platform. In this way, the project not only advanced One Health education but also provided practical tools for educators to promote interdisciplinary STEM learning that connects classroom knowledge to pressing global issues.

Introduction

Interdisciplinary STEM education prepares students to address real-world challenges by integrating knowledge from science, technology, engineering, and mathematics (Honey et al., 2014). This approach helps tackle complex issues like the One Health concept, which links human, animal, and environmental health. One Health has gained prominence due to the need for collaborative solutions to health challenges

that traditional disciplines cannot solve alone. The concept was adopted in the 21st century by organizations like the WHO and FAO. Recent global crises, such as H5N1 and COVID-19, highlighted the importance of integrated approaches to zoonotic diseases (Zinsstag et al., 2011).

This study aims to enhance the understanding of the One Health concept, by highlighting its interdisciplinary nature and its integration of diverse fields.

The specific objectives that have been sought to be achieved through the development of the study are: i) identification and selection of topics to address the concept of One Health; ii) to develop, based on the previous assessment, audiovisual material to explain the One Health concept; iii) to try these animation videos with university students; iv) to develop complementary teaching material, which can be used in secondary school; vi) to disseminate the created material in secondary schools.

Theoretical Framework

STEM plays a crucial role in implementing the principles of One Health due to its interdisciplinary nature.

Interdisciplinary STEM education helps students develop critical skills like problem-solving, communication, and teamwork by engaging them in real-world challenges (Bybee, 2013). It improves their ability to analyze data, consider diverse perspectives, and collaborate effectively. However, opportunities for this type of education are limited due to challenges such as insufficient teacher training, traditional curricula that separate subjects, and a lack of resources connecting different STEM fields (Kelley & Knowles, 2016).

Methodology

Creating the videos

The educational videos were created following these guidelines: i) identifying and selecting topics related to the One Health concept and their alignment with educational standards; ii) developing a storyline to connect the chosen topics; iii) writing the script and dividing it into scenes.

Using the videos with university students

A total of 150 third-year students in Degree in Primary Education have participated in this work, within the subject Didactics of Experimental Sciences: biology and geology, in the modality of small groups, during the 2024-2025 academic year.

To understand the One Health concept, they watched the animation videos and completed pre and post quizzes. We analysed the results and presented them to the students for discussion and clarification of doubts.

These students were grouped into groups of 5 people to create educational activities designed for 1st year of compulsory secondary education students to help them understand the concept of One Health.

Carrying out activities in secondary schools

Each group of university students carried out its activity with a 1st year of compulsory secondary education, moving from the university to the secondary education centres. Therefore, an educational campaign was carried out for the understanding of the One Health concept, through active methodologies, that extended to 30 secondary education classes, encompassing about 900 students.

Results

Educational videos

The first video, lasting 3.25 minutes, covers antibiotic use, resistance, and preventive measures, along with the flow of resistant bacteria between humans, animals, and the environment. The video transcript can be seen in Table 1.

Table 1

Antimicrobial resistance and one health video script.

“Antibiotics are medications that must be taken when prescribed by the doctor in the following situations: To cure infections caused by bacteria and to prevent possible infections prior to surgical procedures and why are there so many restrictions on the consumption of antibiotics? Well, because of a phenomenon called antibiotic resistance, which consists on the ability of bacteria to mutate and develop mechanisms to combat the activity of one or more antibiotics and also to acquire the resistance genes from other bacteria. That is the reason why bacteria are that which become resistant to antibiotics and not the humans with whom they cohabit. Do you know that you can help solving this problem? Firstly, by washing your hands, which always prevents the transmission of microorganisms and therefore also that of antibiotic-resistant bacteria, Secondly by washing food in hygienic conditions and finally by using antibiotics always under doctor's prescription and getting vaccinated. If you have to take antibiotics, remember that a prescription always ends the treatment and if there are any leftovers, take them to the pharmacy back. Young people can also discourage family and friends from taking antibiotics in the case that you see them consuming without a prescription, Do resistant bacteria only affect humans? Not exactly, because bacteria do actually live everywhere and also in our intestines and in those of the animals. They are very abundant and perform very relevant functions for health, but when We use antibi-
--

otics incorrectly, they put pressure on intestinal bacteria and antibiotic-resistant bacteria develop and this also happens in animals. These antibiotic-resistant bacteria pass through dregs to waste water and can contaminate food and environment, and also freeliving animals. Migratory birds can contribute to the spread of resistant bacteria, these can move back to humans or animals and if they cause an infection and are resistant to antibiotics, we will not be able to cure the infection.

Furthermore, a few years ago antibiotics were used as growth promoters. And even more currently there are countries which continue to use them as growth promoters. In other words, as food supplements that help animals grow and accelerate food production. But this is fortunately prohibited in the European Union.

In short, the uncontrolled use of antibiotics accelerates the emergence of resistant bacteria that spread through the existing relationship between humans, animals and the environment to prevent, detect and respond to this challenge, the concept of a single health appears, which is globally known as One Health. One world, one health.”

The second video, lasting 2 minutes, focuses on the impact of diet on climate change. The video transcript can be seen in Table 2.

Table 2

Climate change and diet video script.

“Can our diet influence climate change? Do you know the relationship between your eating habits and greenhouse gases? It is said that to produce 1kg of meat, between 5000 and 20000L of water are needed, and up to 300kg of CO2 is emitted. On the other hand, to produce 1kg of cereal, between 500 and 4000 L of water are needed, and much less CO2 is released than with meat. Globally, intensive livestock farming and agriculture (that is, those that seek to maximize production and minimize costs) produce a third of greenhouse gases and are responsible for a significant percentage of biodiversity loss. At the cost of intensive use of resources, such as fossil fuels, water, fertilizers and pesticides. Furthermore, we are also exploiting seas and oceans; a third of fish stocks are being overexploited for consumption. There are a series of measures that can help to avoid this: reduce meat consumption and ensure that it is from extensive livestock farming (that is, that which takes advantage of the resources of the environment). Eat less processed foods, more fruits, vegetables and legumes to save energy and gain in health. Be careful how much you buy and cook (a third of the food ends up in trash). Choose foods with ecological certification or MSC in the case of fish. Choose, local or nearby seasonal products, avoiding those that had to travel from far away. Less travel, less energy waste and less greenhouse emissions! Take care of your diet... take care of your planet... One world... one health.”
--

Post-survey-based evaluation

A satisfaction survey was conducted among participating students based on 5 questions, evaluated from 1 to 5, with 1 being the most positive value and 5 being the highest (Table 3). The satisfaction survey revealed a very high result in all the questions proposed, as can be seen in Figure 1.

Table 3

Post-survey-based evaluation.

Express your satisfaction with the activity:
A. Do you like activities promoted by the university to be carried out at the school?
B. Participation in this activity has awakened your interest or curiosity
C. This activity has changed your perception about health
D. Reflect your overall opinion about participation in this activity
E. Would you recommend other colleagues to participate in the activity?

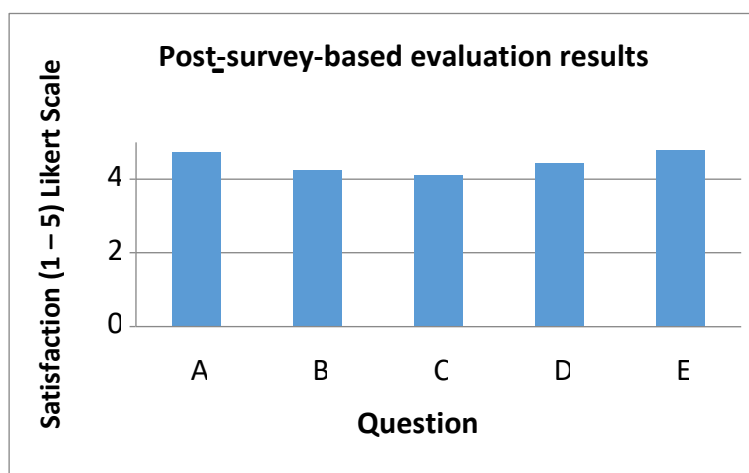


Figure 1. *Post-survey-based evaluation results.*

Discussion

Multimedia has become a powerful tool for advancing interdisciplinary approaches in STEM education, not only because it supports diverse modes of representation, but also because it enables learners to perceive connections between fields that are often taught separately. Students learn more effectively when information is presented through both visual and verbal channels, as long as the design avoids cognitive over-

load. When applied to interdisciplinary contexts, this dual coding helps learners integrate knowledge from multiple STEM domains (Mayer, 2014).

Beyond cognitive processing, multimedia also enhances student engagement and motivation, which is particularly critical in interdisciplinary teaching. Research shows that animations, videos, and interactive modules stimulate curiosity and sustain attention, encouraging students to persist in tasks that draw on multiple disciplines (Atkinson et al., 2024).

Another important contribution is the accessibility and inclusivity of multimedia. Studies in STEM contexts highlight how multimodal learning resources benefit students with diverse needs, including those with disabilities, by offering multiple pathways to understanding (Aghasafari, 2025). In interdisciplinary STEM learning, such flexibility allows all learners to participate in complex, integrated problem-solving tasks.

At the same time, the literature cautions that multimedia is not automatically effective. Poorly designed materials may fragment learning rather than support integration, or create unnecessary cognitive load (Mayer, 2014). Teachers therefore play a central role: they must design or select multimedia resources in ways that align with interdisciplinary goals and scaffold students' navigation across subject boundaries (Zhou et al., 2024). Professional development and institutional support are key if multimedia is to foster genuine integration rather than superficial connections.

In sum, multimedia can serve as a bridge across STEM disciplines by providing multiple representational forms, sustaining engagement, and supporting inclusive learning. Its potential, however, depends on thoughtful design and teacher capacity. Rather than treating multimedia as an add-on, it should be embedded as an integral part of interdisciplinary pedagogy, where it functions to illuminate connections, support inquiry, and enable learners to work with complex, real-world problems.

The study highlights the accessibility of its resources, as the animation videos and all educational materials for understanding the One Health concept are hosted on a WordPress platform <https://www.unirioja.es/no-te-comas-el-planeta/>. This ensures that they are freely available for widespread use by educators and learners, promoting the dissemination of the One Health principles to a broader audience.

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Developing a Course on Nature-Based Solutions for Teacher Education: A Living Lab Case Study

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Keywords: Nature-based solutions (NBS), Initial Teacher Education (ITE), Continuous Professional Development (CPD), Sustainability, STEM education

Abstract

The aim of this study was to develop a course for Initial Teacher Education and Continuous Professional Development in Nature-based Solutions (NBS). This case study, framed within the Living Lab methodology, explores the training needs of teacher educators and teachers in designing and implementing nature-based solutions (NBS) in education and proposes an outline for an NBS course for pre-and in-service teachers. The participants were 10 teacher trainers with experience in the field of didactics in several sciences at the secondary and tertiary education level (i.e., Science Education, Biology Education, Digital Technologies Education, Physics Education, and Environmental Education). Data was collected using a focus group discussion during an online meeting with the participants and was recorded with the use of an online Post-it wall. The data was then analyzed using thematic analysis based on the broader themes of the focus group protocol which was structured in the context of a European-funded project in collaboration with teacher educators and education providers. The thematic analysis revealed a need for training in NBS principles, curriculum integration, and effective communication, alongside practical, ready-to-use resources. Findings inform a draft course outline, to be refined with input from participating countries in the European co-funded project NBS Academy. The ongoing study will result in developing and validating this course to foster NBS teacher education in Europe.

Introduction

Nature-based solutions (NBS) are inspired and supported by nature, they are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience; such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. NBS must benefit biodiversity and support the delivery of a range of ecosystem services (European Commission, 2022). Therefore nature-based solutions (NBS) involve innovative and sustainable solutions where many

challenges are solved by examining nature's ability to solve problems. While teachers play a crucial role in shaping the future, NBS training is essential. NBS education promotes lifelong learning, environmental literacy but also hands-on experiences (European Commission, 2022). Desktop research (Coles, 2020) but at the same time data from a focus group discussion of the study reveals a significant lack of literature, resources, and specialized training programs to assist teachers in incorporating NBS into their educational environments. Educators frequently encounter a shortage of instructional materials and clear guidance on how to integrate NBS principles and practices into their curricula. This absence of easily accessible resources and training opportunities presents a considerable obstacle, impeding teachers' ability to deliver NBS-focused education. To address these gaps, we suggest a course for teachers in NBS to equip educators with the knowledge and tools needed to integrate NBS into curricula, fostering lifelong learning, environmental literacy, and practical solutions to pressing challenges.

Theoretical Framework/Literature Review

NBS are essential in educational settings to address environmental challenges and promote sustainability. Designing and implementing NBS in schools and universities can enhance students' understanding of ecological processes and the importance of sustainable practices. This approach integrates real-world environmental issues into the curriculum, making learning more relevant and engaging. The benefits of NBS in relation to Sustainability in STEM (Science, Technology, Engineering, and Mathematics) education are significant. Firstly, NBS provides hands-on learning experiences that foster critical thinking and problem-solving skills. Students can engage in projects such as creating green roofs, rain gardens, or urban forests, which help them understand the practical applications of STEM concepts in addressing environmental issues (Coles, 2020). Secondly, NBS promotes interdisciplinary learning by connecting STEM subjects with social sciences and humanities. This holistic approach encourages students to consider the social, economic, and environmental impacts of their actions, fostering a deeper understanding of sustainability. Lastly, NBS in educational settings can inspire future generations to pursue careers in sustainability and environmental sciences (Vasconcelos & Calheiros 2022). By exposing students to the benefits and challenges of implementing NBS, educators can cultivate a sense of responsibility and stewardship towards the environment. (Tagulao, 2022). In summary, integrating NBS in educational settings not only enhances STEM education but also prepares students to tackle future environmental challenges with innovative and sustainable solutions.

Methods

The training needs of teacher educators and teachers in designing and implementing NBS in education was explored using the Living Lab methodology. The Living Labs methodology is a co-construction process with the participation of different stakeholders. The participants were 10 teacher trainers with experience in the field of didactics in several sciences at the secondary and tertiary education level (i.e., Science Education, Biology Education, Digital Technologies Education, Physics Education, and Envi-

ronmental Education). Data was collected using a focus group discussion during an online meeting with the participants and was recorded with the use of an online Post-it wall. The data was then analyzed using thematic analysis based on the broader themes of the focus group protocol which was structured in the context of the European-funded project NBS Academy in collaboration with teacher educators and education providers. The themes that emerged from the thematic analysis are presented in detail in the results but were as follows: General Understanding of NBS, Current practises and Experiences, Identifying training needs, Support and resources.

Results

The focus group findings highlighted key needs for NBS training, shaping the course outline. Recommendations include raising teachers' awareness of societal challenges, linking them to NBS principles, and integrating NBS into curricula with real-world examples. Training should combine theory and practice for comprehensive understanding, offer premade materials co-created with stakeholders, include workshops for developing personalized resources, and support fostering environmental awareness. Participants argued the importance of internal support, such as trained school leaders to provide ongoing support, and external resources like funding and partnerships with local stakeholders to sustain NBS initiatives.

Building on these findings, a 12-week course was designed and implemented including 6 modules as presented below:

1. Introduction to NBS
2. Pedagogical methods for applying NBS in formal and non-formal educational settings.
3. Ready-to-use activities and guidance for participants to design their own materials.
4. Strategies for overcoming barriers and sustaining NBS initiatives.
5. Future Directions and Innovations
6. Final Project Presentations

Module 1 introduces the teachers to NBS providing the definition and importance of NBS with case studies around the world employing NBS. This module presents the relevance of NBS in educational settings and highlights the benefits of integrating NBS in curricula with case studies of successful NBS in schools. Module 2 is about designing and implementing NBS in schools focusing on pedagogical methods and strategies in formal and non-formal settings. Module 3 shares a collection of lesson plans and activities to use in class on different topics and calls the participants to design their module materials. Module 4 concerns overcoming challenges in integrating NBS and methods for evaluating and sustaining NBS initiatives. Module 5 shares future directions and innovations as emerging trends in NBS and, Module 6 concentrates on participants presenting their final projects or case studies.

Discussion

This case study revealed a need for training in NBS principles, curriculum integration, and effective communication, alongside practical, ready-to-use resources. At the same time it proposed an outline for an NBS course for pre-and in-service teachers, that was later implemented, in order to bridge the gap and equip educators with the knowledge and tools needed to integrate NBS into curricula, fostering lifelong learning, environmental literacy, and practical solutions to pressing challenges. The course proposed includes specialised training programs to assist teachers in incorporating NBS into their educational environments. The course was piloted during a summer school in July 2025 and will be implemented fully in six European countries to foster NBS teacher education in Europe.

Acknowledgements

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Integrating STEM Activities into the Curriculum: A Bridge from Poverty to Prosperity

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Keywords: STEM education, Teacher training, Professional development, Robotics, STEM clubs.

Abstract

In today's rapidly evolving world, the intersection of education and industry plays a crucial role in preparing students for real-world challenges. This presentation discusses a firsthand experience of the author, who was invited a physics teacher to participate in a three-day training program organised by the regional Directorate of Education. The training exemplifies the importance of fostering collaboration between schools, industrial companies, and association's actors to enhance STEM (Science, Technology, Engineering, and Mathematics) education. Such partnerships not only enrich the educational experience but also bridge the gap between theoretical learning and practical application. By integrating expertise from diverse sectors, this initiative aims to equip students and educators with the tools and knowledge needed to address contemporary societal and technological challenges while building cooperative relationships among stakeholders from diverse sectors.

Introduction

The initiative under study is anchored in a cross-sector partnership that integrates international development expertise, private sector engagement, and local civil society commitment. Such a configuration reflects an increasingly recognised model of cooperation in which diverse institutional actors contribute complementary capacities to achieve shared educational and social objectives. Rather than relying on a single source of support, the initiative is structured around a collaborative framework where each partner assumes a distinct yet interconnected role. The following subsections outline the profile and contribution of each organisation within this partnership.

Partners Supporting the School

CODESPA: Empowering Communities through Development

CODESPA is a non-governmental organisation (NGO) with over 35 years of experience in development cooperation and operates under the honorary presidency of King Felipe VI of Spain. Its mission is to help vulnerable communities in Ibero-America, Africa, and Asia transition from poverty to prosperity through rural market development and entrepreneurship support.

In Morocco, CODESPA (*Educación en medioambiente, emprendimiento y STEM para jóvenes en Marruecos*, sans date) has completed 14 projects and is currently managing 4 active ones, including "Education in Environmental Awareness, Green Entrepreneurship, and STEM Clubs for Adolescents and Youth in Tangier", which runs from January 2024 to December 2026. This project aims to enhance the educational outcomes of 300 adolescents and youth in vulnerable situations through training programs and the creation of 15 STEM clubs in the Tangier region. For more details about this project, visit the CODESPA website.

TEKNIA: Funding and Organisational Support

This project was funded by TEKNIA (*Teknia - Automotive components manufacturer*, sans date), a multinational group specialising in the production of metal and plastic components for mobility solutions. Founded in 1992 in Spain, currently, it operates in 28 locations in 13 countries.

TEKNIA's support for this training aligns with its vision of contributing to innovation and growth, not only within its industry but also in broader educational and developmental contexts. This project is a testament to the company's commitment to fostering educational initiatives that enhance STEM competencies among young learners and educators. Learn more about TEKNIA at their official website.

Chifae: Coordinating Education and Community Development

Serving as the coordinator and facilitator between teachers, the Provincial Directorate of National Education, and CODESPA, the Chifae Association for Development and Training (*Association chifae*, sans date) plays a vital role in ensuring effective collaboration and implementation of educational initiatives. Founded in 1998, Chifae is a non-governmental, non-profit organisation committed to the economic, social, and cultural development of Tangier. For over 25 years, it has focused on education, professional integration, and community development in marginalised neighbourhoods. In cases where schools lack sufficient space, the association makes its premises available to facilitators of this project, ensuring continuity and effectiveness in implementing activities. Learn more about Chifae at their official website.

Tangier-Asilah Directorate: Overseeing Regional Education

The Regional Directorate of the Ministry of National Education (*Educación en medioambiente, emprendimiento y STEM para jóvenes en Marruecos*, sans date), Preschool, and Sports – Tangier-Asilah is located in northern Morocco, within the Prefecture of Tangier-Asilah, which belongs to the Tangier-Tetouan-Al Hoceima region. This prefecture covers an area of approximately 891 km² and includes the city of Tangier and its surrounding areas. Geographically, it occupies a strategic position at the crossroads between Africa and Europe, and is distinguished by the rare feature of having coast-

lines on both the Atlantic Ocean and the Mediterranean Sea. The directorate oversees a broad educational network comprising 353 schools (primary, collegial, and secondary) according to the statistics of the 2023–2024 academic year. The total school population is around 302,000 students, of whom approximately 58,000 are enrolled in the private sector.

Training day's

The three-day training began with an intervention by the representative of CODESPA in Morocco, with a detailed presentation about the project's objectives (*Educación en medioambiente, emprendimiento y STEM para jóvenes en Marruecos*, sans date). The initiative aims to enhance STEM education by benefiting 300 students from secondary schools. To achieve this, 15 sciences teachers were invited to participate in the training, held from 11 to 13 November 2024 in Ten Gran Mogador Hotel. Each teacher is expected to voluntarily establish and supervise a STEM club within their respective institutions, ensuring that at least 20 students per school benefit from the club's activities. TEKNIA Company led sessions throughout the training days on human resources management. Meanwhile, the representatives of the Regional Directorate of Education delivered a presentation on inclusive education, efforts in addressing the challenges faced by students with special needs and highlighting successful experiences in this area. The directorate also contributed by providing a team of three technology professors to offer theoretical explanations of robotics and programming concepts, complemented by practical workshops in line with the need to inspire students and link educational materials to real-world applications (Zaza et al., 2019). These workshops included programming the Arduino board to operate a 4-LED lighting system on the first day. On the second day, participants developed a gas detection system equipped with sound and light alarms, as well as an automatic fan activation mechanism. The final session focused on assembling and programming the MBot2 robot to perform tasks such as detecting and following a path with colour recognition, navigating a specific route, and stopping upon detecting an obstacle.

The progression of activities carried out during the three training days is illustrated in the figures below (Figures 1, 2 and 3). These images capture some practical workshops, providing a visual account of how the sessions moved from introductory programming tasks to more advanced applications in robotics and automation.

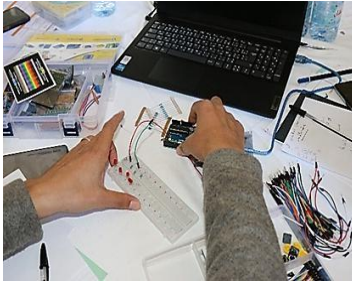


Figure 1. Programming Arduino Board to Operate a 4-LED Lighting System.

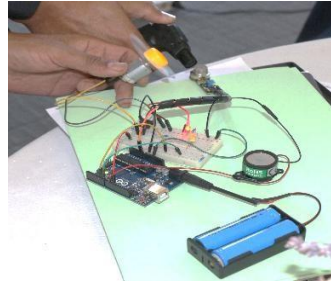


Figure 2. Development of a Gas Detection System with Sound and Light Alarms and Automatic Fan Activation

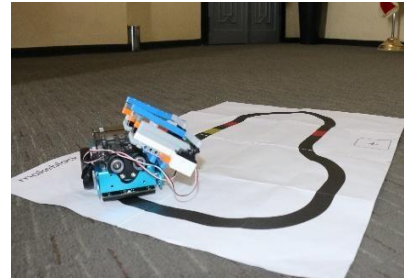


Figure 3. Assembly and Programming of the MBot 2 Robot to Detect and Follow a Path with Colour Recognition, Navigate a Specific Route, and Stop Upon Detecting an Obstacle

Field Notes and Reflections

The program is consistent with the findings of recent research (Hobbs et Kelly, 2020), which suggests that such initiatives contribute to enhancing teachers' skills and expanding their understanding of real-world applications of technology and engineering.

Furthermore, discussions among the educators during the sessions reflected a notable interest and enthusiasm, and such lived experiences, similar to findings from previous study (Geyer *et al.*, 2013), demonstrating the transformative potential of a such collaboration.

Sustainability and Challenges in STEM Collaboration

An important dimension of initiatives such as this lies in their contribution to sustainability in STEM education. Beyond offering training sessions, the provision of materials—such as robotics kits, Arduino boards, and sensors—ensures that resources remain in schools after the training is completed. This creates lasting opportunities for students to continue experimenting, innovating, and applying their knowledge in practical contexts. By leaving behind durable equipment and teaching materials, the initiative promotes continuity and scalability, enabling schools to integrate STEM activities into their regular curricula and fostering a sustainable culture of inquiry-based learning.

Apart from this regional project, cooperation can occur at multiple dimensions. Local partnerships may form between a school and a company (Geyer et al., 2013), international initiatives such as ECB-InGenious demonstrate collaborative efforts across borders (Kudenko, Simarro et Pintó, 2017). Moreover, partnerships can involve a small number of schools and industrial partners (Hobbs et Kelly, 2020).

On the 25th of November 2024, a team of four individuals representing all the stakeholders delivered educational materials to my school, including two Robot Kits

(mBot and mBot2), two Arduino learning kits, and a 37 Sensor Kit. However, this project did not address the critical role parents play in shaping their children's educational and career aspirations, particularly in STEM fields. Actively involving parents in STEM initiatives is essential, as their support can greatly enhance students' enthusiasm and willingness to pursue careers in science, technology, engineering, and mathematics (Zaza et al., 2019).

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A Case Study on Professional Development Training of Pre-Service and In-Service STEM Teachers

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Keywords: effectiveness, accessibility, transferability, professional development content

Abstract

This study investigates the effectiveness, accessibility, and transferability aspects of professional development content developed in Turkey under the European Union-supported ICSE Academy-proSTEM project. The study was conducted using the case study design from qualitative research methods and is based on the views of three teachers and two international observers who participated in an online session. Data were collected through semi-structured interviews and reflection forms and analyzed using content analysis. Findings indicate that the online session contributed to teachers' argumentation focused thinking, recognition of argument components, and practice of daily life. It is also understood that it has the potential to contribute to the management of classroom discussions and pedagogical knowledge. Furthermore, it was determined that the online and evening session format increased participation, digital tools facilitated collaboration, and the content was transferable to different educational levels and international contexts.

Introduction

In the 21st century, science, technology, engineering, and mathematics (STEM) fields are of strategic importance for countries' economic development and innovation capacity. However, international reports reveal that there is a persistent shortage of qualified labour in STEM fields across Europe (Cedefop, 2024). Labor shortages in STEM fields have been extensively discussed in various reports and studies (e.g., Cedefop, 2016). Three primary factors are often identified as contributing to these shortages. The first is the failure to train sufficient students in STEM fields. The second is the qualification challenges faced by STEM educators. Finally, graduates who will work in STEM fields are not qualified to meet market demands (Smith & White, 2024). Moreover, it is known that science and mathematics teachers are among the groups with the least international mobility in the EU (European Commission, 2021) and that teachers are unable to take full advantage of collaboration based learning opportunities (Schleicher, 2018). In this context, the effectiveness, accessibility, and transferability of profes-

sional development programs are considered critical for building a sustainable STEM ecosystem that enhances teacher capacity for STEM education.

The ICSE Academy-proSTEM project, supported by the European Union, aimed to support the professional development processes of pre-service and in-service STEM teachers by focusing on the competence problems faced by STEM educators from an innovative perspective. Within the scope of the project, the demands and needs of STEM educators were determined, educational contents were created in line with these needs, and the qualifications of the participants were attempted to be increased through the academic activities carried out.

In this study, the effectiveness, accessibility, and transferability to different contexts of the educational content developed in Türkiye within the scope of the ICSE Academy-proSTEM project were investigated. The effectiveness aspect *refers to* growth in teachers' content knowledge, teachers' pedagogical knowledge, teachers' pedagogical content knowledge, development of their classroom practice, developing teachers' beliefs, motivation, and competence in self-reflection. Accessibility refers to the ability of the training to meet the needs of the participants in terms of content, pedagogical approaches used, program, duration, and digital tools needed. Finally, transferability reflects the applicability and utilization potential of the training in other countries, regions, and schools.

The study seeks to answer the following question: What are the views on *the effectiveness, accessibility, and transferability of the professional development training content prepared for pre-service and in-service STEM teachers in Türkiye?*

Methodology

Research Design and Participants

The research was conducted using the case study design, one of the qualitative research approaches (Yin, 2014). This design allows for an in-depth examination of a phenomenon in its real-life context. The study investigated the effectiveness, accessibility, and transferability aspects of an argumentation-based professional development activity on the theme of sustainability, conducted in Turkey as a job shadowing activity within the scope of the ICSE Academy-proSTEM project.

The session was conducted online with 39 participants (20 female, 19 male) in the evening (8 pm). The data for the study were collected from three teachers who volunteered to participate in this session and two experts from two different European countries. The teachers work in different types of schools and have different backgrounds; one is a science teacher in a rural area, one is a preschool teacher in a multicultural school, and the other is a science teacher with an engineering background. The experts are two researchers specializing in science education and argumentation pedagogy. The researcher leading the activity holds a PhD in argumentation and teaches argumentation at the master's level. This diversity ensured that data was collected from

different professional and cultural perspectives, thereby enhancing the depth of the research.

Implementation Process

The session was conducted online via Microsoft Teams and structured around the theme of sustainability. A total of 39 teachers and teacher candidates participated in the 80-minute session. The implementation process proceeded in an interactive format. The session began with a short warm-up activity designed to capture participants' attention, starting with the question, "Which argument is more persuasive?" Toulmin's Argument Model (Toulmin, 2003) (claim, data, warrant, backing, qualifier, and rebuttal) was then introduced; teachers developed arguments using this framework. Participants then worked in small groups in Breakout rooms and shared their arguments digitally via Padlet. At the end of the session, each group presented its argument to the participants and received feedback in a discussion setting.

Data Collection and Analysis

Data were collected through semi-structured interviews, a reflective form based on the experts' observations of the activity, and a second reflective form based on the experts' process of transferring the observed activity to their own region. The collected data were analysed using qualitative content analysis. The data from the interviews and reflective forms were coded independently by two researchers, and the findings were addressed in terms of effectiveness, accessibility, and transferability. The reliability of the study was ensured through data diversity and participant validation. The interview and reflection data were compared to check for consistency; some of the findings were shared with the participants and revised based on their feedback.

Findings

Effectiveness

The views obtained regarding the effectiveness of the session carried out are stated below.

- The session provided teachers with the opportunity to recognize Toulmin's argumentation components (claim, data, warrant, backing, qualifier, and rebuttal) and relate them to their daily lives.
"During the process, I could see how teacher students become aware of the key elements involved in argumentation (the situation, the claim, the argumentation, the evidence, the relationship between the claim, the circumstances, and the evidence, etc.)" (Expert 1)
- To gain an understanding of how discussion can be realised in classroom practice
"The pedagogical knowledge offered has to do with how to manage a classroom about argumentation, where you mainly teach through the examples and learning contexts provided, and how you guide students' reasoning and discussion about them. In this case, this is also closely linked to the pedagogical content knowledge

required to provide a meaningful lesson about argumentation based on active learning.” (Expert 2)

- Understanding the importance of data and graphics in argumentation practices “... *I learned that the graphs are qualifiers. I understood the importance of them. For example, when I was reading an article, I used to skip over graphs. I don't do that anymore, so that means they are qualifiers...*” (Teacher 3)
- Integration of technology in the realisation of experiments and demonstration of examples of its use

“...There, for example, [the photosynthesis experiment] is an example of how technology is now integrated into lessons. Or how to make experiments more technological, how to shorten the time, or how to make them more concrete? The sensor example there was very good, I took a note of it...” (Teacher 3)

Additionally, it was noted that the session offered perspectives on the academic report and project writing process, had sufficient content, and addressed European Union priorities. However, participants were hesitant in the early stages of the online session, and online participation remained limited; it was noted that icebreaker activities and structured roles could mitigate this issue.

Accessibility

The views obtained regarding the accessibility of the session held are outlined below.

- It has been emphasized that the online evening session facilitates access. “*It was good that it was evening; it's hard to gather people in one place these days.*” (Teacher 2)
- The use of digital tools such as Padlet (Web 2.0) has supported collaborative participation and sharing of evidence.
“...I think the training was very productive. Because of that Padlet, using web tools effectively. I think they are very useful...” (Teacher 2)
- Participants mentioned that the session was quite short and that they weren't familiar with the online platform.
“It would have been more useful if it had been longer.” (Teacher 1)

Transferability

The comments obtained regarding the transferability of the implemented activity to different regions and contexts are listed below.

- The argumentation understanding gained can be used by teachers in the contexts of different courses.
“...From now on, when I plan my lessons, I will always plan them according to what I have learnt here. What is the evidence for this knowledge? What could be the data? What reasoning process might individuals have gone through when they put forward this knowledge? What is the warrant for

it? What is the qualifier for it? ... I think I will do it this way according to the subject of the lesson..." (Teacher3)

- Experts have been able to simplify and adapt the session to their own countries (adapting the Toulmin model with three components: data, results, justification).

Discussion

The findings indicate that the session contributed to teachers' argumentation-focused thinking, recognition of argument components, and implementation in daily life. It is also understood that it has the potential to contribute to classroom discussion management and pedagogical knowledge. This situation can be evaluated as a reflection of S-TEAM (2010), indicating that teachers need support to carry out argumentation activities in their classrooms in a sustainable manner. Therefore, the participants' views on the effectiveness of the activity indicate that they are not pedagogically familiar with the argumentation process and that the activity helped them reach various understandings, thus pointing to their need for support. The session's addressing of how technology can be used in the argumentation process demonstrated parallels with the technological pedagogical content knowledge model (Koehler & Mishra, 2009) by ensuring the integration of pedagogical and technological knowledge in terms of effectiveness.

Conducting the online session provides opportunities for access in one way (Hodges et al., 2020), but on the other hand, competence in using technology and time have emerged as limitations (Hrastinski, 2008). Finally, the fact that argumentation is a widely known pedagogy among researchers has added transferable potential for different grade levels, local contexts (Osborne et al., 2004), and countries. Furthermore, the fact that the topic addressed in the event included the theme of sustainability and incorporated European Union priorities created opportunities for transferability.

Conclusions and Recommendations

The study findings reveal that the draft training content has significant strengths in effectiveness, accessibility, and transferability. In terms of effectiveness, the training content enabled participants to improve their content knowledge, pedagogical knowledge, and pedagogical content knowledge while enhancing their classroom practices. Concerning the accessibility aspect, it is seen to provide accessibility in terms of the duration and format of the course, pedagogical approaches, and digital tools used. Finally, in the transferability aspect, it is understood that both the participant teachers can transfer their acquisitions to different regions, schools, and levels, and that the expert observers can transfer them to other countries and education levels.

Finally, researchers can longitudinally examine the effectiveness, accessibility, and transferability aspects of the professional development content they will develop, and conduct studies using cross-country multi-case analyses.

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Sustainable Professional Development for Technology Teachers in Primary and Lower Secondary Education: Building Networks and Competence through Peer Collaboration

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Keywords: Peer collaboration, Technology education, Primary and lower secondary teachers, Continuing Professional Development (CPD), STEM/STEAM networks

Abstract

Technology education is a relatively young school subject in the Swedish curriculum and is often taught by teachers without formal qualifications. This creates challenges for ensuring high-quality teaching, particularly in primary and lower secondary education. To address these challenges, a collaborative Continuing Professional Development (CPD) project was launched in spring 2025, targeting technology teachers in grades F–3 and 4–6. The project was a joint effort between Jönköping University, Upptech Science Centre, and practising teachers, inspired by the ICSE Academy and the EU-funded proSTEM initiative. Its aim was to strengthen teachers' pedagogical content knowledge, promote peer learning, and build sustainable networks for continued professional growth. The programme consisted of three workshops, each designed with specific goals: hands-on exploration of construction tasks, classroom implementation, and peer shadowing. Teachers engaged in practical activities such as building moving mechanisms and buzz wire games, which they later introduced to their pupils. They also observed colleagues' lessons and took part in reflective discussions about effective teaching strategies. Findings showed enhanced teacher confidence, greater creativity in student work, and a strong desire for sustained collaboration. Teachers highlighted the value of sharing experiences, reflecting on their practice, and connecting with both the university and the science centre. The artistic and playful elements of the activities were particularly effective in engaging students and extending the scope of technology education. The project demonstrated that even short-term, practice-based CPD can make a meaningful difference for technology teachers. By combining theory with hands-on learning and collegial exchange, the initiative supported teachers in developing competence, confidence, and community—three essential pillars for sustainable professional development in STEM education.

Introduction

Technology education plays a crucial role in preparing students to understand and navigate in a rapidly evolving, technology-driven society. Despite its importance, the school subject is still relatively young in the Swedish curriculum and is often taught by teachers without formal qualifications in the field. This situation generates challenges for both the quality and consistency of technology education, particularly in primary and lower secondary education.

In response to these challenges, a collaborative professional development initiative was launched in the spring of 2025, targeting technology teachers in grades F–3 and 4–6. The project was a joint effort between Jönköping University, Upptech Science Center, and practicing teachers, and was inspired by the European ICSE Academy and the proSTEM initiative. Participants were recruited through local school principals and volunteered to take part, resulting in a group of 14 teachers. The aim was to strengthen teachers' pedagogical content knowledge, foster peer learning, and build sustainable networks for continued professional growth.

The training consisted of hands-on workshops, peer shadowing, and reflective discussions, enabling teachers to exchange experiences and explore effective teaching strategies. By combining practical classroom activities with collegial collaboration, the project sought to empower teachers to develop engaging and meaningful technology education for young learners.

Literature Review

Connecting Theory and Practice in Technology Education

Technology education in primary and lower secondary schools presents unique challenges due to its interdisciplinary nature and the rapid pace of technological change. Many teachers lack formal training in the subject, which can lead to uncertainty and low confidence in their teaching. Bandura's theory of self-efficacy (1997) provides a useful lens here: individuals' belief in their own capabilities—particularly when reinforced through mastery experiences—is central to motivation and performance. In professional development, hands-on activities and opportunities for successful implementation can significantly enhance teachers' self-efficacy.

Shulman's (1986) concept of Pedagogical Content Knowledge (PCK) further highlights the importance of combining subject expertise with pedagogical strategies. For technology teachers, this means not only understanding technical concepts but also transforming them into meaningful learning experiences for young students. The process of didactic transposition (Bosch & Gascón, 2006) is particularly relevant, as it describes how scientific knowledge is reshaped into teachable content. Teachers must navigate this transformation while ensuring both accessibility and subject integrity.

Recent studies (Nordlöf, 2024; Hallström et al., 2023) underline the value of authentic, practice-based teaching approaches. By connecting classroom activities to real-world contexts, teachers can increase both engagement and understanding. Such approaches also provide teachers with concrete experiences that strengthen their con-

confidence and competence. The integration of creative and artistic elements into technology teaching has further been discussed in the context of STEAM education, highlighting the potential of playful, design-oriented tasks to engage a broader range of learners.

The Role of Collegial Learning and Professional Networks

Collaborative teacher training has emerged as a key strategy for supporting educators in complex subject areas such as technology. McLaughlin and Talbert (2006) emphasise the value of school-based learning communities, where teachers engage in shared reflection and peer collaboration. Such communities foster belonging and provide ongoing support, which is particularly important for teachers who may otherwise feel isolated in their subject area.

Peer shadowing and collegial dialogue, as implemented in the present project, align well with these principles. Observing each other's lessons and discussing effective practices not only provides new insights but also develops a shared professional language. In this way, collaboration supports the creation of sustainable networks that extend beyond individual schools and institutions.

Together, these perspectives highlight the importance of combining practical experience, reflective dialogue, and structured support in professional development for technology teachers. They also point to the need for CPD initiatives to be contextually relevant, inclusive, and firmly grounded in both research and practice.

Methods

This CPD project was designed as a short-term, practice-oriented training course for technology teachers in grades F–3 and 4–6. The project was carried out during spring 2025 and involved collaboration between Jönköping University, Upptech Science Centre, and 14 practising teachers from local schools. Teachers were recruited through their principals, and participation was voluntary, which ensured a motivated group while also limiting the representativeness of the sample.

The programme consisted of three structured workshops, each designed with specific goals:

Workshop 1 – Hands-on Exploration

Teachers engaged in practical activities such as constructing moving mechanisms (mechanical and electrical) and building buzz wire games. These tasks were intended to stimulate creativity and provide concrete examples of classroom-friendly technology activities.

Workshop 2 – Implementation and Reflection

Between the first and second meetings, teachers implemented one of the construction activities with their pupils. During the second workshop, participants shared their experiences, discussed levels of student engagement, and reflected on both challenges and successes.

Workshop 3 – Peer Shadowing and Collegial Learning

Each teacher conducted a peer observation of a colleague’s technology lesson. The final meeting focused on sharing insights from these observations, discussing effective teaching strategies, and identifying elements of successful practice.

Throughout the programme, emphasis was placed on collegial dialogue, reflective practice, and the integration of theory and hands-on learning. The initiative also sought to strengthen connections between schools, the university, and the science centre, thereby fostering a sustainable professional network.

In addition to the structured workshops, data on teachers’ experiences were collected through a short survey distributed via Esmaker and a focus group interview held during the final meeting. The survey included questions on teachers’ self-confidence in teaching technology, the usefulness of different learning strategies, and the value of professional networking. This allowed all participants to share their views anonymously. The focus group then provided deeper insights into how the teachers perceived the CPD format, its classroom relevance, and its impact on their practice.

Results

The project generated several notable outcomes related to teacher engagement, instructional confidence, and student learning.

Enhanced Teacher Confidence and Collegiality

Teachers reported that the combination of practical activities and peer collaboration significantly increased their confidence in teaching technology. The opportunity to observe colleagues and discuss authentic classroom experiences was described as both inspiring and reassuring. Many participants expressed appreciation for the chance to reflect on their own practice while learning from others.

Increased Student Engagement and Creativity

Teachers observed that students responded enthusiastically to the hands-on construction tasks. Although pupils were given the same assignment, they produced highly diverse results, demonstrating creativity, problem-solving skills, and perseverance. The integration of artistic and design-oriented elements—often referred to as the “A” in STEAM—proved particularly effective. By combining technical construction with creative expression, teachers were able to engage a broader range of learners, including those who might not normally be drawn to technology-related activities.

Value of Short-Term CPD

Participants emphasised that even a brief training course can make a meaningful difference. The structured design, clear objectives, and practical classroom relevance were key to its success. Teachers also highlighted the importance of support from their principals in ensuring participation and recognition of the training.

Need for Continued Support and Networking

The project revealed a strong desire among teachers to maintain lasting networks and strengthen their connections with both the university and the science centre. Many expressed interest in further collaboration and stressed the importance of continued access to resources, research, and opportunities for collegial learning.

Discussion

The professional development project carried out in spring 2025 provided valuable insights into the needs and experiences of practising technology teachers in grades F–3 and 4–6. Despite its short duration, participants reported meaningful growth in both confidence and competence, underscoring the potential of targeted, practice-based CPD.

One of the most significant outcomes was the sense of empowerment that emerged through peer collaboration. Teachers valued the opportunity to observe each other's lessons and to engage in reflective dialogue about what constitutes effective technology teaching. This collegial exchange fostered a deeper understanding of pedagogical strategies and encouraged teachers to adapt and refine their own practice.

The hands-on activities were particularly well received. Teachers noted that students responded with enthusiasm and creativity, often producing diverse and imaginative solutions to the same task. This highlighted the importance of integrating practical, construction-based learning into technology education. Furthermore, the artistic dimension of the activities added a valuable layer to learning, resonating with STEAM approaches that emphasise the interplay between technical skills, design, and creativity.

Teachers also expressed that the CPD format—combining workshops, classroom implementation, and peer shadowing—was both manageable and impactful. While many participants lacked formal qualifications in technology, they found that even a short, wellstructured training course could significantly boost their confidence and motivation. The intervention demonstrated that CPD does not need to be extensive to be effective; relevance, practicality, and peer support are crucial.

At the same time, certain limitations must be acknowledged. The project involved a relatively small group of self-selected teachers, which may limit the transferability of findings. Moreover, the outcomes reported here are short-term; it remains to be seen whether the increased confidence, competence, and collegial engagement are sustained over time. Future research should therefore explore the long-term impact of short CPD interventions in technology education and examine how networks can be maintained and expanded.

In summary, the project showed that short-term, contextually grounded CPD can make a tangible difference for technology teachers. By focusing on peer learning, hands-on activities, and reflective practice, the training supported teachers in building

competence, confidence, and community—three essential pillars for sustainable professional development.

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Insight into how to promote girls' entrepreneurial mindset within a STEM context

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Keywords: STEM education, non-formal education settings, girls, entrepreneurship, mindset

Abstract

Entrepreneurial skills are highly valued for the current society but the interest on this sector, namely concerning STEM and among girls, remains relatively low, contributing to a significant gender gap. Nevertheless, this study shows that STEM education provides an ideal context for developing entrepreneurial skills while fostering greater involvement of girls in science. Finally, some considerations are discussed into how to design effective interventions to achieve this goal.

Introduction

One of the European priorities for addressing the challenges of a fastchanging society is fostering an entrepreneurial mindset (Stergiou & Filippidis, 2023). However, this concept extends beyond studying economics or management, or pursuing a career in entrepreneurship. An entrepreneurial mindset involves the ability to transform knowledge into value or ideas into products. It requires innovation readiness, as well as technical, management, and personal maturity skills (Kutzhanova et al., 2009). These skills align closely with the principles of STEM education, which focus on critical thinking, problem-solving strategies and responsible decision-making processes (Kaya-Capocci et al., 2024).

Despite this alignment, students' entrepreneurial mindset is typically underdeveloped, particularly among girls, leading to a workforce that lacks female entrepreneurs (Poggesi et al., 2020). The aim of this study is to shed light on effective educational intervention to address this gap.

Theoretical framework

The development of an entrepreneurial mindset is crucial for personal and professional success in the 21st century. This mindset encompasses a set of skills and attitudes, such as innovation, proactivity, and risk-taking, which enable individuals to identify opportunities and create value (Bolton & Lane, 2012). Research indicates that these skills are not innate but can be cultivated and strengthened through targeted and well-designed educational experiences (Bécharde & Toulouse, 1991).

STEM education could offer a particularly fertile ground for this development, as it inherently promotes problem-solving, critical thinking, and creativity, which are found

dational pillars of entrepreneurship (Nair et al., 2017). Integrating entrepreneurial concepts into STEM learning, a concept known as Entrepreneurial STEM Education, has been shown to enhance students' resourcefulness and problem-solving abilities (KayaCapocci et al., 2024). This pedagogical approach creates a synergistic environment where scientific knowledge is applied to real-world challenges, turning abstract ideas into tangible solutions or products.

However, a significant gender gap persists in both STEM fields and entrepreneurship. Women are underrepresented in STEM education, careers, leadership roles, and especially in STEM entrepreneurship (Treanor, 2022). Research by Poggesi et al. (2020) highlights the multiple barriers women face in STEM entrepreneurship, underscoring the need for targeted interventions. Such programs must provide girls not only with technical skills but also with the confidence and inspiration to pursue entrepreneurial paths. Entrepreneurship education can have gendered effects; Pergelova et al. (2023) found that it can differently influence the feasibility, desirability, and intentions for technology entrepreneurship among male and female STEM students, reinforcing the need for gendersensitive program design.

Methods

As part of the GEM project, which seeks to empower girls by fostering their digital and entrepreneurial potential, ten European institutions organized two editions of STEM summer camps. In Spain, this initiative focused on providing an immersive experience for around 60 girls aged 13 to 18 who spent a week engaging with female leaders in STEM, digital, and entrepreneurial sectors within the region.

During the 2022 edition, specific efforts were made to introduce girls to entrepreneurship within STEM fields. The program included workshops showcasing real-life examples of young female entrepreneurs in STEM. Other workshops encouraged participants to develop hypothetical prototypes addressing societal needs and to pitch their ideas to potential investors. Additionally, participants worked in small groups on their own research projects under the guidance of female research mentors, presenting their findings at the GEM conference at the end of the camp.

The general goal of this camp was to inspire and enable girls around Europe to tap their STEM, digital and entrepreneurial potential that was articulated allowing girls to acquire knowledge about STEM (specially related to the ICT sector) and its world of work, about inspiring role models, to develop transversal skills and an entrepreneurial mindset

While the impact of the 2021 and 2022 camp editions in the attitudes of girls towards STEM was measured and confirmed by Martín-Peciña et al. (2024), the last target concerning entrepreneurship remained unexplored.

For that purpose, to assess the impact of this initiative on participants' entrepreneurial mindset, a pre-post test methodology was used by means of the Individual Entrepreneurial Orientation (IEO) instrument (Bolton & Lane, 2012) measuring entrepre-

neurial orientation. Data were analyzed using non-parametric statistical tests and cluster analysis of paired preand post-responses.

Table 1

Details on the research instruments applied (pre/post approach)

Dimension	N Items	Cronbach's alpha	Translated exemplary item*
Risk-taking (IEO)	3	0.88	I would be willing to invest effort and resources in something that could be very productive.
Innovativeness (IEO)	4	0.85	I prefer to experiment with new ways of solving problems instead of doing the traditional way.
Proactiveness (IEO)	3	0.81	I usually act in anticipation of future problems, needs, or changes.
STEM attitude	8	0.81	I am interested in learning about STEM.

*Items responses in 1-to-5 Likert agreement scale

Results

After the camp, participants showed improvements in both their STEM attitudes

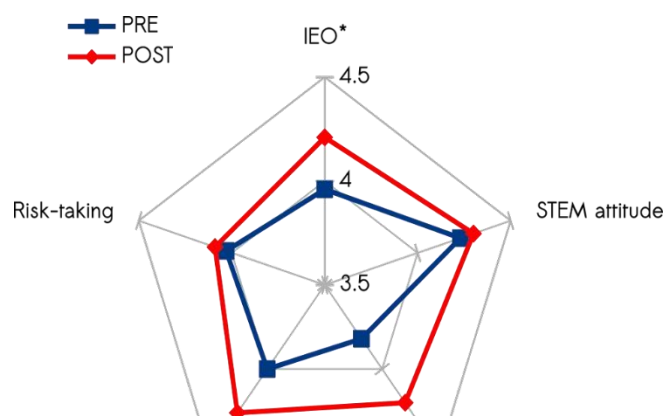


Figure 1. Pre-post values for IEO (and its dimensions) and STEM attitudes.

and entrepreneurial orientation (Figure 1). As expected from a voluntary STEM initiative, participants already exhibited great STEM attitudes in the pre-test. However, their entrepreneurial orientation was initially lower but improved significantly ($p=0.010$) reaching the STEM attitude level, with particular gains in the proactiveness dimension of the IEO construct ($p=0.013$). As shown in Figure 2, there was a strong correlation be-

tween improvements in STEM attitudes and IEO ($R=0.60$, $p<0.001$). Cluster analysis revealed two size-balanced groups of participants with differing levels of gains in STEM

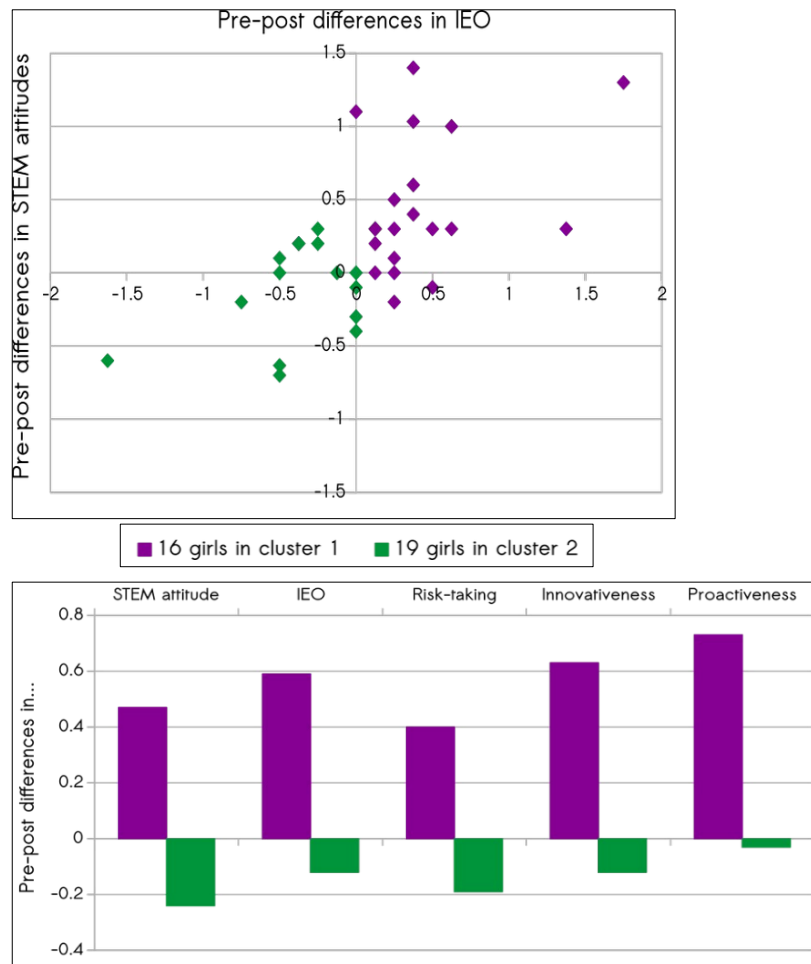


Figure 2. Values of gains in STEM attitudes and IEO showing a positive correlation (left) and different gains between two clusters of girls (right).

attitudes and entrepreneurial orientation, with one cluster showing improvements in both aspect significantly higher than the other ($p<0.05$).

Responses to open-ended questions provided additional insights on which camp aspects girls valued and enjoyed more. Participants noted that while too many talks on entrepreneurship could be monotonous, especially in virtual formats, they greatly valued the practical aspects of the camp. Some participants suggested that starting with a practical workshop for ice-breaking and team building might be challenging for introverted girls.

Table 2

Translated girls responses to post-test open questions about the summer camp strengths (+) and weaknesses (-).

	<i>"I have understood how women have a key role in science even though sometimes it does not seem so."</i>
	<i>"I now know different perspectives on science and what can be done from each of them."</i>
	<i>"They help you see both science and the world of work that they offer us from different perspectives."</i>
+	<i>"I have felt very supported by all people here."</i>
	<i>"I didn't have much knowledge about science, but this year I've learned about entrepreneurship and innovation."</i>
	<i>"At school, it's almost all theory, but at this camp it has been more practical, I've enjoyed it more."</i>
	<i>"What I liked the most was getting immersed in the project and the hands-on session by Ximena [entrepreneurship]."</i>
	<i>"I haven't liked the long video conference talks."</i>
-	<i>"The group workshop about inventing an object on the first day might make some introverted girls feel uncomfortable." "Too many unengaging talks."</i>

Discussion

The results demonstrate that STEM education provides a suitable context for fostering entrepreneurial orientation, at least among girls. Therefore, it is possible to influence girls' interest and involvement in science and entrepreneurship through controllable factors. This aligns with recent research suggesting that well-designed interventions can shape entrepreneurial mindset (Barth & Muehlfeld, 2022). For instance, a study by Shahin et al. (2021) of 193 secondary school female students in Australia found that a female-focused STEM-based entrepreneurship program significantly increased their entrepreneurial intention.

A key lesson learned is that participants valued the overall camp experience, especially the interactions with mentors, the sense of community, and the hands-on workshops, more than lectures on entrepreneurship alone. The strong correlation found between gains in STEM attitudes and IEO suggests that fostering a passion for science can simultaneously nurture an entrepreneurial spirit. This supports the concept of Entrepreneurial STEM Education, which embeds entrepreneurship within scientific practice as a powerful approach for enhancing students' resourcefulness and problem-solving skills (Kaya-Capocci et al., 2024). The participants' preference for practical sessions over "unengaging talks" reinforces this idea; entrepreneurial skills are best learned through active, hands-on engagement, not passive reception (Neumeyer & Santos, 2020).

These lessons can be transferred to the formal school context. By integrating practical, autonomous, and collaborative learning, and connecting students with female role models, educators can help bridge the gender gap in both STEM and entrepreneurship. This approach not only develops the technical and management skills necessary for enterprise development but also builds the confidence and personal maturity required to see themselves as future innovators and leaders.

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Obstacles and achievements of a STEM Fair in a Primary Education University Degree

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Keywords: STEM education, project-based learning, formative assessment, teacher education, professional development

Abstract

A Pre-service Primary teacher (PSPT) formative Project Oriented Learning STEM experience in Spain is analysed. The experience was included in one of the subjects for the second year. The participants were 131 second year university students working in small groups. The process was mentored by two teachers and was supported by formative assessment instruments. The project products were measuring instruments for physical magnitudes built for a STEM Fair, a short video about the building process, and a reflective report of the experience. The fair was a success, and the learning goals were achieved for most of the degree students, but the process had some obstacles related to some students' lack of commitment to learning that are related here.

Introduction and theoretical framework

According to the Spanish mandatory curriculum (Ministry of Education and Vocational Training, 2022), the primary teachers must plan and propose activities and learning situation to develop STEM competences. In this regard, educational research, have shown the value of interdisciplinarity and potential in school science (Martín-Páez et al, 2019; Bassachs et al. 2020; Diego-Mantecón et al., 2020). Nonetheless, the reality in schools shows that primary teachers do not feel sufficiently prepared to teach these contents in practice. Teachers' perception of insufficient training is one of the reasons why science and technique activities are not carried out properly in some schools. Therefore, initial teacher education should focus more on addressing the constraints that teachers report.

However, current teacher training curricula maintain the traditional compartmentalised structure of scientific areas, depriving their teaching of practical and real meaning. At the same time, there are major obstacles among Spanish undergraduate students of Education Degrees: fear of science, feelings of incompetence in relation to its teaching, and dropping out of subjects (Brígido et al. 2011). In addition, in many cases, teacher training, both initial and ongoing, does not promote practical professional knowledge that satisfactorily integrates theoretical knowledge and alternative and innovative teaching models (Jeong et al., 2016).

Teacher training should be directed towards the development of reflective capacity and autonomy, as well as providing criteria for decision-making. In this sense, it is essential to get closer to the real context, to reduce the distance between theory (the university degrees) and practice (the children and the primary school) in a critical and reflexive way (MartínezMínguez y Flores, 2014). In fact, despite the proven impact of practical experiences (*Practicum*) on the training of future teachers (Colomo and Gabarda, 2021), they rarely provide concrete experience in teaching science *sensu lato*.

Fortunately, there are primary teacher training experiences that have yielded good results. The development of workshops based on STEM methodology during the initial training of primary school teachers offers promising results in terms of scientific knowledge, perception of self-efficacy, and the generation of motivating emotions towards teaching and integrating scientific and technological concepts to their future students (Mateos Nuñez et al., 2024). As well, it has been proved that Project Oriented Learning (POL) methodology has positive aspects in terms of reality adaptation and work mentoring (Barba et al., 2012; Nieva et al., 2023). In addition, it has stood out the power of assessment for learning (Wiliam, 2011) or formative assessment in Higher Education (Panadero et al., 2019; Nieva et al., 2023).

Research questions and purposes

Taking on the challenge of improving the training of primary school teachers we follow Stenhouse's recommendation to research into our own practice: "Teacher should be able to describe to a colleague what happens in his classroom. To make it possible we need more research which starts from practice" (Stenhouse, 1971 cited by Elliott, 2024, p. 709). Then, the two main purposes of the teacher training experience analyze here are to learn as teacher trainers and share the experience, and to reflect about the obstacles and achievements of the teaching and learning processes.

The main question that guided this study was: Is it possible to implement an integrated STEM project with a big group of students at a university teacher trainer degree?

Research methodology

Description of the training experience

Context description

The STEM Fair project was included in the subject: "Curriculum development in experimental sciences" carried out the school year 2023/24. This is a compulsory second-year subject in a Primary Education University Degree in Spain, has 6 ECTS credits and takes place before the *Practicum*. The participants were 131 university students (44 men) organized into two reference groups, four practice groups, and 34 small work groups. The students were guided by two teachers.

STEM project description

The project was compulsory for all students of the subject, and its aims were a) to experience an engineering design project; b) to develop STEM knowledge; c) to have first teaching experience.

The process was supported by a guide (description of the process, timeline, and quality requirements), formative assessment activities and instruments (Peer-review template, Auto-assessment rubric relative to teamwork and Auto-assessment one point rubric relative to learning goals of the project). It was implemented for two months.

Each team had to generate three products of the project: a measuring instrument of a physical magnitude built for the STEM Fair (preferably made from waste material), a short video about the building process, and a reflective report of the experience. The steps, tasks and places of the project appear in Table 1, in which the actions and tasks related to formative assessment are shown in bold.

Data collection instruments

The research tools were the lectures' diary, the assessment instruments of the project, the project products (measuring instrument, report and video), an open-ended question in the final exam and a voluntary and anonymous questionnaire.

Table 1

Brief description and timeline of the STEM project

Action or Task	Product / place	Date or deadline
Presentation to the reference groups	Classroom and virtual campus	March 2024 (19 th & 20 th)
Design and construction of a thermometer in a practical session	Practice report / laboratory	March (21 st & 22 nd)
Selection of magnitude and the measuring instrument. Pre-design or sketch of the instrument. Teamwork	Brief report / Virtual campus delivery	April 8 th
Follow-up, discussion, raising questions or solving problems with the teachers at least once	Diverse campus places	April-May
Group-work in practical sessions (mentoring)	Laboratory	April 11 th & 12 th & May 2 nd & 3 rd
Report writing and self-assessment	Virtual campus delivery	May 12 th

Peer- assessment among randomly as- signed groups (“peer-review”)	Virtual campus delivery	from May 13 th - 17 th
STEM Fair	University campus	May 21 st -24 th
Final report and video	Virtual campus delivery	May 31 st

Analysis

The data were analyzed quantitative and qualitative, categorized manually, without software help.

Main findings, obstacles, and achievements

The students learned science, engineering and technology, but math was poorly developed in some cases. Learning the process for engineering design was one of the goals of the project, and it was necessary to explain and redefine several times since it was the first time for the students (the instrument had to be secure, useful and precise).

The STEM Fair was successful for all (Figure 1). During the fair some students faced difficulties explaining the usefulness of the instruments to children from 1st to 4th year of Primary Education (ages 6 to 10). Nevertheless, the schoolteachers considered the experience interesting for themselves and inspiring for children, they reported the children’s enthusiasm after the fair: “children have spent several weeks tinkering and inventing all sort of things”.



Figure 1. Some STEM Fair moments

The selection of the magnitudes and measuring instrument was problematic for some teams, and it was impossible to avoid repetition. The easier instruments were the most popular ones. Some teams broke up because of internal tensions during the process, and as a result, some students worked alone (Table 2).

In addition, there were some rare cases of uncritical work (avoiding the process of design-prototyping-analysis-redesign), and inadequate use of generative AI to fill in the peer-assessment forms.

The students that answered the questionnaire highlighted the formative experience tagging it as “practical”, “interactive”, “innovative”, “experimental”, “enriching”, “useful”, “exciting” and “meaningful”.

Table 2
Measuring instruments built and student teams

Magnitude	Measure strument	in- Teams ies	/Cop- Team composition (number of stu- dents)
Air pollution	Cotton wool with Vaseline	1	3
Atmospheric humidity	Hygrometer	3	3, 2, 1
Atmospheric pressure	Barometer	5	4, 4, 3, 5, 1
Density	Density meter	2	4, 4
pH	pH measurement	2	4, 4
Quantity of matter (Mass)	Pan balance	1	4
	Roman/ Steel-yard balance	1	6
Rainfall	Rain gauge	4	5, 6, 3, 2
Speed	Meter & chronometer	1	5
Temperature	Thermometer	1	1
Time	Hourglass	3*	4, 4, 2
	Water clock	2	3, 4
	Sail-clock	1	5 5
	Sundial	1	
Weight	Dynamometer	1	2
	Scale	1	5
Wind direction	Weather vane	1	2
Wind speed	Anemometer	4	6, 4, 4, 1

**One of the hourglasses used water and oil instead of sand.*

Discussion and conclusion

The STEM project was motivating and helped students in their professional development. Assessment activities were naturally embedded in the teaching and learning processes helping students learn and gain experience in formative assessment. The reflection about the possibilities and challenges of this STEM education experience could be useful and inspiring for teacher educators as well as primary teachers. Likewise, the

limitations found suggest the need to keep working on the reflective thinking processes of PSPT, especially the development of cooperative work is needed.

It is possible to implement an integrated STEM education project with a large group of trainee teachers. But, in the current context, there is the added challenge posed by generative AI (Almasri, 2024) and it seems appropriate to include regulated and ethical use.

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STEM out-of-school activities to learn and to protect

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Abstract

This workshop showcased and discussed outcomes and examples from the EU-funded project MOST (icse.eu, 2020-2023) in which European school students, teachers, and citizens developed science knowledge, transversal skills, and competencies in so-called School-Community-Projects (SCPs). The MOST Project consortium consisted of 23 partners from 10 European countries (higher education institutions, schools, non-formal education providers, ministries, municipalities, and enterprises). The project opened up formal science education, established partnerships between schools and their communities (science education providers, citizens, businesses, and others), and worked jointly on environmental school-community projects. In the workshop, four examples were shown to give good insight into: 1) how those SCPs worked out during the MOST project; 2) how this contributed to strong and innovative STEM Education; 3) how was this continued after the Most project? How sustainable is the cooperation? In all examples we describe the opportunities to learn about the central issues in those projects, and we make the connection with 'taking care' and protecting our planet.

Introduction

The ETE IV focused on implementing and scaling up innovative teaching approaches in STEM education, particularly open schooling initiatives concerning environmental issues. Experiences and results gained from the MOST project (2020-2023) were presented and reflected upon (Doorman and Maass, 2023). Central to the MOST approach were the School Community Projects (SCPs). In ETE V we also show the connection to the ICSE Expert Group 'STEM Out'.



Figure 1. The elements of a School Community Project (SCP)

SCPs are supported by communities of practice, a mix of teachers, STEM-education scientists, and others who work together. Hazelkorn (2015) writes: "Collaboration between formal, non-formal and informal educational providers, enterprise and civil society should be enhanced to ensure relevant and meaningful engagement of all societal actors with science and increase uptake of science studies and science-based careers and employability and competitiveness" (Hazelkorn, 2015, p. 32).

Theoretical Framework

At the moment, Europe faces a shortfall in science-knowledgeable people at all levels of society. This is a good time to expand opportunities for science learning in formal, non-formal, and informal settings¹. Evidence shows that European citizens, young and old, appreciate the importance of science and want to be more informed, and that citizens want more science education. Over 40% believe science and technological innovation can have a positive impact on the environment, health and medical care, and basic infrastructure in the future. Therefore, collaboration between formal, nonformal, and informal science education providers, enterprises, and civil society should be enhanced to ensure relevant and meaningful engagement of all societal actors with science, and increase the uptake of science studies, citizen science initiatives, and science-based careers, employability, and competitiveness. We need responsible research and innovation (RRI), the process of aligning research and innovation to the values, needs, and expectations of society. We need science to inform citizens and politicians in a trustworthy and accessible way.

We use Open schooling as an important vehicle for local and regional collaboration: schools and their surrounding communities (museums, science centers, and others) work together in projects to make clear that formal and informal can have strong connections.

¹ https://cordis.europa.eu/programme/id/H2020_SwafS-01-2018-2019-2020

Within the ICSE-consortium collaboration (icse.eu) of the last 10 years, we have become more explicit about how to start, run, and evaluate open schooling projects (Doorman and Maass, 2023; Kapelari, Weinberg, 2023), and in this contribution, we give four examples of Open schooling projects.

Example 1 - Netherlands - Techkwadraat

Through a one-off National initiative involving 80 regional networks, Techkwadraat (techkwadraat.nl) aims to raise the level of technical education and promote a technology-inclusive culture. The approach consists of three programme lines: 1) a participation programme to create mass participation based on proven approaches, 2) an innovation programme to generate new solutions to persistent problems, and 3) a knowledge programme for cross-regional activities (including national policy advice and image improvement). In 2024 more than 50 regional projects started for age group 5 to 18 years, with a variety of objectives on digital literacy, maker spaces education, sustainability education, bridging activities between science and mathematics, inquiry learning, etc., all linked with technology. In all cases regional industry, musea and all kinds of science center initiatives are involved, in order to add an open-schooling setting and enforce collaboration between educational and other institutions.

Research (Keijzer et al., 2025; Duifhuis et al., 2025; Doorman et al., 2023; Van Dijk et al., 2023) makes clear that alongside this collaboration it is important to invest in regional and local communities of practice, where teacher training institutes and research institutes also participate. Initial impressions confirm that local and regional co-operation between education and extracurricular activities is an important building block for giving meaning and connecting to current social issues.

Example 2 - Czech Republic - Food and sustainability

In the Czech Republic, we focused on those topics of the circular economy that are linked to the Sustainable Development Goals established by the United Nations in 2015 (UN, 2015), in particular Goal 12 – ensuring sustainable consumption and production patterns. Since food and packaging waste is a major issue in the Czech Republic, the schools implemented SCPs called “Food Waste in the School Canteen” and “Without Packaging”. As an example, we can briefly describe one SCP in the form of a project day focused on the environmental topic “Waste and the Environment” (Bednarova et al., 2020). Students aged 14–15 participated in an intensive one-day programme on the topic “Plastics and Their Impact on the Environment”. During this project day, they were introduced to the issue using several instructional methods (video presentations, text work, a lecture by an expert, an experimental part, and a productive workshop). The aim of the project was mainly to learn the content related to the topic of plastics and to develop positive attitudes towards waste reduction. The project activities were monitored through students’ mind maps, essays, and interviews to identify changes in

their knowledge and attitudes. The data obtained from all stages of the research showed positive results regarding the participants' knowledge. This means that the number of relevant terms in the mind maps increased significantly. In addition, the study confirmed the potential for a "teacher's project" to evolve into "students' mini-projects" focused on creating their own artefacts.

Example 3 - Norway - Use of low-cost virtual reality for teaching and learning in STEM

Virtual reality (VR) is a technology that have been used now for decades, originally mainly for flight simulators and games, the last decades for several teaching and learning purposes, as well. Really deep learning outcome of using such technology is still debated, but there are situations that are situated for the use of such technology, related to economy, logistics or the need of making a situation more realistic and immersive than using other media or technology. Pantelidis (2009, pp. 62-64) is discussing situations that are suitable and less suitable for the use of VR-tours. Among others she is mentioning the following situations as suitable for: "when travel, cost, and/or logistics of gathering a class for training make an alternative attractive" and when "a training situation needs to be made really real." At the teacher education at Norwegian University of Science and Technology (NTNU) we have used low-cost (here defined as costing maximum 500 EUR for a 360 camera + a headset) VR in several STEM (inclusive sustainability and climate change) topics since 2018. We have tested a number of approaches, from teacher production of traditional 360-degree VR field-course teaching material, to real-time livestream field-trips (Cyvin & Grindeland, 2025). Many of the teaching situations have been connected to climate change issues at situated out-of-school arenas. At the moment we preferable use this technology as small VR-introductions to a field-area in front of field trips, or to introduce students to remote areas which is too expensive or time-consuming to visit. Our most frequent use is however to let students themselves in groups make their own 360-degree VR tours as part of tasks or portfolio exam assignments (Cyvin & Grindeland, 2025). Through this we have changed the student role from consumers to active producers of knowledge, and the teacher role from being a knowledge provider to being a coach, in line with Oost's (2011) model and characteristics of a discovery- or enquiry-based field-work.

Through students' evaluations and feedback, we have shown that this way of using VR gives valuable supplement to other learning tools, and the portfolio VR assignments were highly appreciated by the students. But we also got clear advice from students to not let such technology replace real field-trips (Cyvin & Grindeland, 2025; Favier et al., 2021).

Example 4 - Austria – School garden for sustainable nutrition

Supermarkets respond to societal consumption habits by offering a wide variety of groceries. However, their packaging and the products that remain unsold, ending up as food waste, represent a major issue for the global carbon dioxide footprint (Scholz et al., 2015). Beyond this, modern society is urged to adapt its diet to avoid aggravating

problems such as biodiversity loss, water pollution, and to contribute to climate change mitigation (Potter et al., 2022).

In response to these challenges, students from an Austrian secondary school initiated an Open Schooling project with their teacher, who inspired colleagues to join. Following the INCREASE Trail Map of the MOST project, the students took the lead in INViting potential stakeholders interested in sustainable food practices. During the co-CREation phase, they worked together to identify challenges, align diverse interests, and develop shared goals. Subsequently, the participants moved to the Act phase, where students, community members, and other stakeholders collaboratively designed and implemented strategies to establish a school garden that promotes sustainable nutrition. Finally, they shared their outcomes widely and conducted an evaluation to reflect on successes and areas for improvement. Now running successfully for five years, the project continues to thrive. The enthusiasm, responsibility, and joy of working in the garden are passed down each year to younger students, ensuring long-term engagement and awareness of sustainable food practices. Through this ongoing Open Schooling initiative, the school community demonstrates how education and collaboration can effectively address sustainability challenges.

Example 5 - Turkey – STEM festivals

STEM festivals (stemandmakers.org) serve as key platforms for showcasing School–Community Projects (SCPs), promoting co-creation of knowledge, and encouraging partnerships among students, teachers, scientists, local businesses, and policy-makers. The MOST Fair, held in conjunction with the STEM & Maker Fest Expo in Nevşehir, Türkiye, attracted more than 2,000 participants over two days. During the event, students presented their SCPs, initiated intellectual discussion and arguments, and participated in various STEM activities, while community members engaged in hands-on learning experiences (Sardag & Cakmakci, in press). The festival thus contributed to promoting students’ science capital, enhancing public engagement with STEM, and promoting scientific literacy within the community.

STEM festivals provide collaborative spaces where students, teachers, and citizens co-create knowledge through inquiry-based learning and encourage young people to become agents of change by pursuing research careers in STEM fields. By showcasing student projects, scientific demonstrations, and innovative solutions, these events bridge formal and informal education while fostering curiosity and creativity. They also strengthen community ties by encouraging families and citizens to participate actively in science learning, thereby building trust between schools and society. Moreover, STEM festivals promote inclusion by reaching diverse audiences and inspiring lifelong learning. As visible showcases of open schooling outcomes, they can influence policy and highlight the societal value of collaborative, real-world STEM education. During the MOST project, virtual science fairs were also organized. These online events represent a viable alternative to traditional in-person festivals, offering broader accessibility and

sustaining student engagement in STEM education (Kaya, Sardag, & Cakmakci, in press).

Conclusion

The presented findings underscore the power of Open Schooling initiatives and School-Community Projects (SCPs), as developed within the EU-funded MOST project (2020-2023), to foster innovative STEM Education. Crucial to their success is the enhanced collaboration between formal, non-formal, and informal educational providers, enterprises, and civil society. This partnership is vital for boosting engagement with science and addressing the societal shortfall in science-knowledgeable people.

The five showcased examples illustrated how SCPs engage students, teachers, and citizens in relevant environmental issues and sustainability themes, emphasizing 'taking care' and protecting our planet. Examples spanned from addressing food and packaging waste in the Czech Republic to establishing school gardens for sustainable nutrition in Austria. Moreover, utilizing low-cost Virtual Reality in Norway demonstrated the shift of the student role from consumers to active producers of knowledge. Through this participatory approach, schools become effective agents of community well-being, leading to a raised interest in science, scientific literacy, and environmental responsibility. The results confirm the potential for sustainable and long-term educational engagement.

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The TINKER Framework: Revolutionising Informatics Education with Authentic and Gender-Inclusive Pedagogy

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Keywords: Informatics education, Authentic learning, Gender inclusion, Pedagogical framework.

Abstract

In Europe, informatics education is confronted with enduring challenges, including limited advanced ICT skills among students, inconsistent incorporation of pedagogy into curricula, and significant gender disparities in both educational settings and the ICT workforce. To address these issues and rethink informatics education at the upper primary and lower secondary levels, the Erasmus+ TINKER project has been established. Developed through comprehensive desk and field research, the TINKER Pedagogical Framework merges authentic learning with gender-inclusive practices, structured around four interdependent pillars: informatics competencies, authentic learning, gender inclusion, and teacher professional development. Collectively, these pillars provide a flexible and research-based framework for cultivating inclusive, engaging, and forward-looking learning environments. By aligning technical knowledge with socially responsive pedagogy, the TINKER Framework contributes to the European agenda for digital education, promoting systemic innovation and enhancing participation in STEM fields.

Introduction

The digital transition is a priority within the European Union (EU), as highlighted by the Digital Education Action Plan 2021–2027, which underscores the importance of innovative pedagogical approaches to foster interest in STEM careers and dismantle gender stereotypes (European Commission, 2020). Although progress has been made in acquiring basic digital skills, the development of advanced ICT competencies remains insufficient. In 2021, only 42% of EU graduates aged 20–24 exhibited above-basic digital skills, with even lower percentages in several partner countries, such as Cyprus (29%) and Italy (34%) (Eurostat, 2022). These statistics underscore the pressing need for consistent and effective strategies in teaching informatics.

Alongside skills gaps, European education systems are undergoing curricular reforms in Informatics. However, much of the professional development for teachers continues to prioritise curriculum delivery over pedagogy. The COVID-19 pandemic

has further exposed disparities in teachers' ICT competencies, underscoring the necessity for systemic capacity building (Kosmas et al., 2022). Without focused professional learning initiatives, the potential for innovation and digital inclusion may remain insufficiently developed.

One significant challenge is the ongoing gender imbalance in the field of Informatics. In Europe, women represent only 19% of ICT specialists, with comparable underrepresentation in partner countries (Eurostat, 2022). Additionally, female enrollment in ICT-related tertiary programmes remains disproportionately low compared to that of men. This gender disparity in informatics education is not confined to differences between boys and girls; it also encompasses broader diversity issues, as many students face barriers stemming from prevailing stereotypes and inadequately inclusive practices (Christou et al., 2022). These observations highlight the urgent need for gender-inclusive pedagogical approaches that address hidden curricula and foster equitable opportunities for all participants.

In light of this context, the TINKER project (2024) was initiated under the Erasmus+ programme, encompassing ten partners from Cyprus, Greece, Belgium, Ireland, the Netherlands, Croatia, and Italy. The project aims to revolutionise informatics education in upper primary and lower secondary schools through a pedagogical framework that integrates authentic learning with gender-inclusive practices. It was developed to tackle three interconnected needs to:

1. Improve ICT skills acquisition by aligning informatics education with clearly defined competencies.
2. Strengthen teachers' capacity to adopt authentic pedagogical practices that foster engagement and creativity.
3. Promote gender inclusion in Informatics, counteracting stereotypes and widening participation.

The objectives outlined are implemented through the TINKER Pedagogical Framework, which encompasses four interdependent pillars: informatics domains and competencies, authentic learning experiences, gender inclusivity, and the professional development of teachers. The TINKER Framework serves as a research-informed roadmap aimed at promoting equitable, authentic, and forward-looking informatics education throughout Europe.

The TINKER Pedagogical Framework

The TINKER Pedagogical Framework was developed to offer a coherent and research-based response to the fragmented landscape of informatics education across Europe. Its design is grounded in comprehensive desk and field research carried out in partner countries, including analyses of curricula, focus groups with teachers, and national needs assessments (TINKER project, 2024). The framework addresses three interconnected challenges: the lack of advanced ICT skills among students, insufficient

pedagogical integration in curriculum reforms, and ongoing gender disparities in participation and career pathways (Eurostat, 2022; European Commission, 2020).

To address these challenges, the framework incorporates four interdependent pillars:

1. Informatics Areas & Competencies
2. Authentic Learning
3. Gender Inclusion
4. Teacher Professional Learning

These pillars are not standalone components; rather, they function as mutually reinforcing elements. Collectively, they offer a structured yet flexible roadmap for schools to create meaningful, engaging, and inclusive informatics education. Figure 1 depicts the conceptual model of the TINKER Pedagogical Framework.

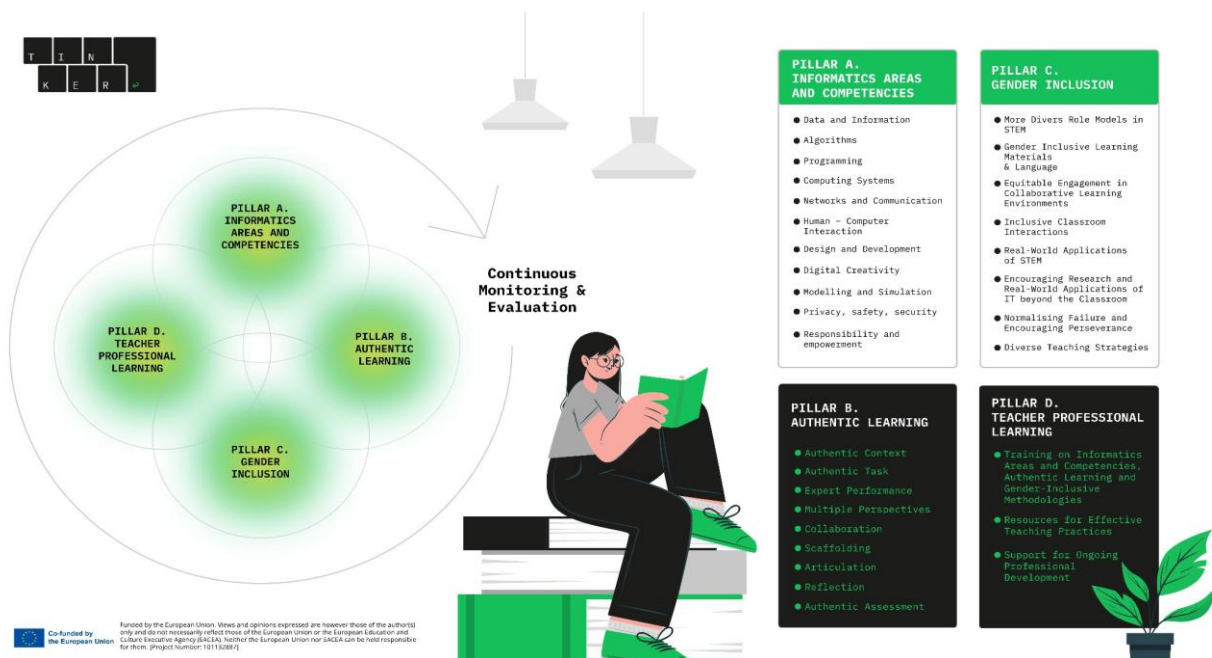


Figure 1. *TINKER Pedagogical Framework*

Informatics Areas & Competencies

The first pillar is based on the Informatics4All Reference Framework, which identifies eleven core areas essential for informatics education: data and information, algorithms, programming, computing systems, networks and communication, human-computer interaction, design and development, digital creativity, modelling and simulation, privacy, safety and security, and responsibility and empowerment (Informatics4All Coalition, 2019). By adopting this framework, TINKER establishes a common foundation applicable across various national contexts, while allowing for contextual adaptations. For instance, in primary education, students may start with foundational

tasks such as organising digital information or engaging in simple block-based programming. As they transition to lower secondary education, they progress to more complex topics, such as algorithm design or cybersecurity. This progression embodies a developmental approach that merges foundational literacy with the advanced competencies needed in digital societies (Caspersen et al., 2022).

Authentic Learning

The second pillar is rooted in the tradition of authentic learning, which situates knowledge within meaningful, real-world contexts. Herrington and Oliver (2000), along with Herrington et al. (2014), highlight principles such as authentic context, collaborative tasks, reflection, and genuine assessment as crucial for fostering deep engagement. In TINKER, authentic learning is realised through activities in which students develop solutions that hold real-world significance. A notable example is the design of a digital library system, where students collaborate to create databases, consider user experience, and present their prototypes to both peers and teachers. These tasks not only facilitate the integration of various informatics concepts but also promote collaboration, problem-solving, and creativity.

Gender Inclusion

The third pillar addresses the ongoing inequalities present in informatics education. Research indicates that stereotypes, hidden curricula, and a lack of inclusive practices can deter many learners, especially girls, from pursuing informatics (De Wit et al., 2023; Happe & Buhnova, 2018). Gender-inclusive pedagogy entails the implementation of intentional strategies to promote equitable access and engagement. This includes the use of inclusive language, the presentation of diverse role models, and the structuring of classroom interactions to foster balanced participation (Christou et al., 2022; McClure, 2000). For instance, teachers might develop projects that highlight the social relevance of computing, such as utilising data analysis to support environmental sustainability initiatives. These projects challenge conventional stereotypes by framing Informatics as socially impactful and interdisciplinary, thus appealing to a broader spectrum of learners.

Teacher Professional Learning

The final pillar highlights that meaningful reform can only be achieved when teachers receive adequate support. Evidence from the COVID-19 pandemic revealed that varying levels of ICT skills among teachers posed a significant barrier to digital inclusion (Kosmas et al., 2022). The findings from the compiled report across partner countries (TINKER project, 2024) further stress the importance of targeted professional learning to address these disparities. Therefore, TINKER places a strong emphasis on continuous professional learning, which encompasses both pre-service and in-service education. This includes structured opportunities such as workshops and micro-credentials, as well as collaborative professional learning experiences where

teachers work together to design and reflect on authentic scenarios. The focus is on equipping teachers with the confidence and pedagogical repertoire necessary to seamlessly integrate informatics concepts, authentic practices, and inclusive strategies into their everyday teaching.

The distinctive value of the TINKER Framework lies in the interconnectedness of its four pillars. A single classroom project can effectively target informatics competencies (Pillar A), be crafted as an authentic, real-world task (Pillar B), incorporate gender-inclusive practices (Pillar C), and foster teacher professional growth (Pillar D). Additionally, the framework includes a cyclical process of monitoring and evaluation, ensuring that practices are continually adapted to evolving contexts (TINKER project, 2024). In this manner, the TINKER Pedagogical Framework serves not only as a theoretical structure but also as a practical guide for transforming informatics education into an inclusive, engaging, and future-oriented discipline.

Discussion and conclusion

The TINKER Pedagogical Framework addresses key gaps in informatics education by integrating clearly defined informatics competencies with authentic and gender-inclusive pedagogical approaches. By emphasising real-world tasks, the framework enhances student engagement, while its gender-inclusive practices challenge stereotypes that hinder participation. Additionally, professional development for teachers fosters sustainability and systemic change.

Despite these advancements, challenges persist in achieving consistent curriculum integration and securing long-term policy support. Nevertheless, the framework offers a flexible and adaptable model that can be customised to suit various contexts. Notably, the TINKER project advances the European agenda for digital education by providing a research-informed framework for upper primary and lower secondary education. Aligning technical knowledge with authentic experiences and inclusivity, it paves the way for meaningful, equitable, and forward-looking informatics education.

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RoboAquaria: Robotics in aquatic environments to promote STEAM and environmental awareness

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Keywords: STEAM, robotics, environmental awareness, sustainability, marine literacy

Abstract

The RoboAquaria Project is an initiative focused on promoting STEAM education and marine environmental awareness through the innovative use of Educational Robotics. The project targets primary and secondary school teachers, school leaders, and policymakers, equipping them with tools to address the climate crisis and foster sustainable behaviors in school communities. Through the development of a Marine Robotics Curriculum, Guidelines for Teachers, Toolkits for building RoboAquaria, and E-Learning Resources, the project supports the integration of robotics into interdisciplinary curricula. Policy Recommendations have also been produced to guide systemic changes in STEAM and sustainability education. While, key stakeholders from Cyprus, Italy, Greece, Croatia and Ireland, including universities, educational centers, and schools worked on the project, this paper will focus on presenting the RoboAquaria Framework and the results of its piloting with students and teachers in Cyprus.

Introduction

STEAM engagement supports the development of critical thinking, collaboration, and innovation among young learners (Reinking & Martin, 2018). Yet, international assessments such as PISA 2018 reveal that more than one in five European students perform below baseline in mathematics and science (OECD, 2019). At the same time, the urgency of the climate crisis underscores the need to equip students with environmental literacy and sustainability competencies (European Commission, 2020). Introducing environmental and marine education early has been shown to positively shape pro-environmental behaviors, with effects that extend to peers, families, and communities (Świątkowski et al., 2024). Educational robotics has emerged as an effective approach to merging digital skills development with hands-on, interdisciplinary learning. The RoboAquaria Project leverages this potential, combining robotics, STEAM, and marine education to foster sustainability values and digital readiness, while aligning with EU priorities such as the European Green Deal and “Environment and fight against climate change”. By integrating robotics with real-world environmental challenges, the project positions students as active problem-solvers, while providing teachers with structured resources, professional development, and policy frameworks.

RoboAquaria theoretical framework

Marine literacy

A core dimension of RoboAquaria is the promotion of marine literacy, which helps learners understand the vital interconnections between oceans and human life (Cava, Schoedinger, Strang, & Tuddenham, 2005). Building marine literacy is increasingly urgent in the context of climate change, given the ocean's role in regulating weather, sustaining biodiversity, and providing essential resources (United Nations, 2022). Embedding this perspective in education promotes pro-environmental values and behaviors, particularly when introduced at a young age. By situating robotics within marine contexts, RoboAquaria leverages this literacy as both scientific knowledge and a framework for sustainability education (UNESCO, 2021).

Educational robotics and marine robotics

Another central component of RoboAquaria is the use of educational robotics to connect STEAM learning with real-world problem solving. Robotics has been widely recognized as a tool for hands-on, constructivist learning that builds computational thinking, creativity, and collaboration (Eguchi, 2016). Extending this into aquatic contexts through marine robotics provides a novel way for students to explore environmental systems, simulate ecosystems, and test technological solutions to sustainability challenges (Duarte et al., 2021).

Environmental education

RoboAquaria also draws on principles of environmental education, aiming to cultivate ecological awareness and sustainable citizenship. Environmental education is essential for preparing learners to understand and act on global ecological challenges, equipping them with critical knowledge and responsibility (UNESCO, 2017). Evidence shows that when marine and environmental education are integrated with hands-on, experiential projects, they generate stronger behavioral intentions and community-level impact (Chawla & Cushing, 2007; Świątkowski et al., 2024). In this way, RoboAquaria situates robotics within a pedagogical tradition that emphasizes reflection, responsibility, and local action.

STEAM education

RoboAquaria is designed around a STEAM approach, expanding traditional STEAM by embedding creativity, design, and the arts. STEAM enables educators to frame robotics and marine education in authentic, real-world contexts that appeal to diverse learners (Perignat & Katz-Buonincontro, 2019). This integration has been shown to broaden participation, enhance problem-solving, and strengthen innovation, particularly among underrepresented groups (Henriksen, 2014). Within the project, STEAM provides a unifying framework that links technology, sustainability, and creativity, preparing students with both technical skills and the capacity to imagine socially relevant solutions to environmental challenges.

Methods

The project adopted a participatory design approach, actively involving teachers, school leaders, policymakers, and researchers across partner countries. Initial activities included desk research, focus groups with in-service teachers, and curriculum mapping to ensure alignment with evidence and national priorities. In Cyprus, national focus groups engaged teachers and experts to identify effective pedagogical strategies such as project-based, inquiry-based, and challenge-based learning, along with peer-to-peer learning, design thinking, and storytelling. The project's main outputs included a Marine Robotics Curriculum, Teacher Guidelines, RoboAquaria Toolkits, E-learning resources, and Policy Recommendations at both national and EU levels. Across Italy, Croatia, Greece, Cyprus, and Ireland, partners piloted the RoboAquaria curriculum through 92 classroom activities, which were evaluated using shared KPIs, lesson rubrics, pre- and post-questionnaires for students, and teacher reflections.

Results

RoboAquaria Foundations

A cumulative report documented best practices in Cyprus from related initiatives, including: the RoboGirls Project (2020–2022), which empowered girls in STEAM through robotics and coding (Robogirls, 2022); the Robotex Cyprus Festival and sCY-ence Fair (2023), which showcased how robotics and science fairs enhance collaboration and problem-solving; and the Digitally Supported Learning Environment (2021–), developed by the Cyprus Pedagogical Institute, which integrates robotics, AR/VR, and 3D technologies into curricula.

Key findings from the pilot activities

The pilot activities tested robotics-based lessons that integrated coding, STEAM, and marine sustainability. Across the five partner countries, the piloting of RoboAquaria demonstrated strong educational outcomes. Learning objectives were achieved or exceeded in more than 90% of lessons, showing that the curriculum effectively supported both technical and interdisciplinary goals. Student engagement was consistently high, particularly during hands-on construction, coding, and problem-solving activities, where learners could see immediate results from their work. Teachers also displayed notable adaptability, adjusting lesson pacing, strategies, and support to address technical issues, time constraints, and the diverse needs of their students without compromising learning outcomes (*Figure 1*).

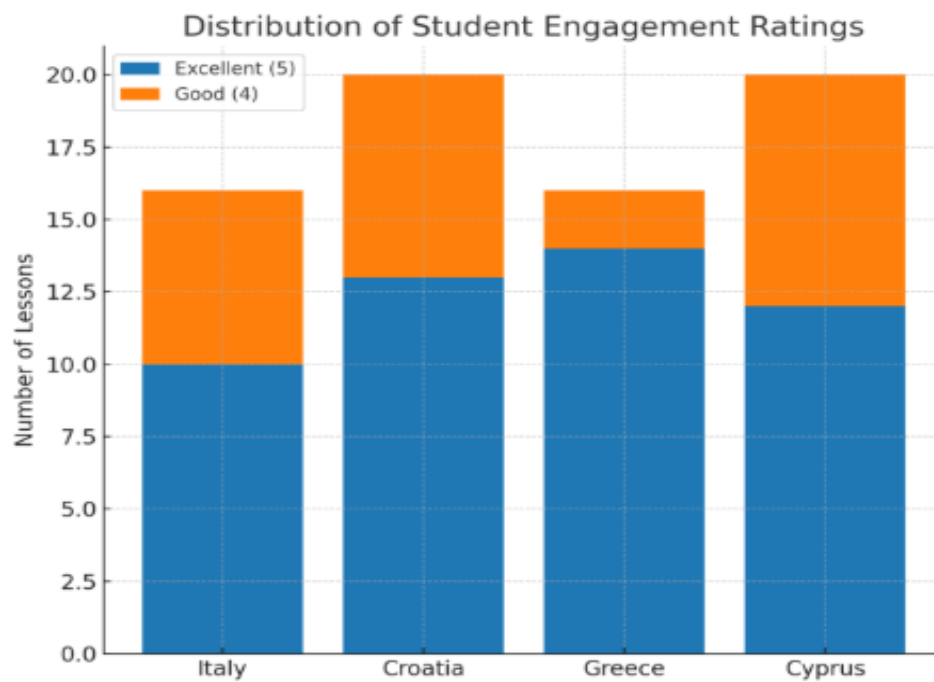


Figure 1. Distribution of Student Engagement Ratings Across RoboAquaria Pilot Lessons and

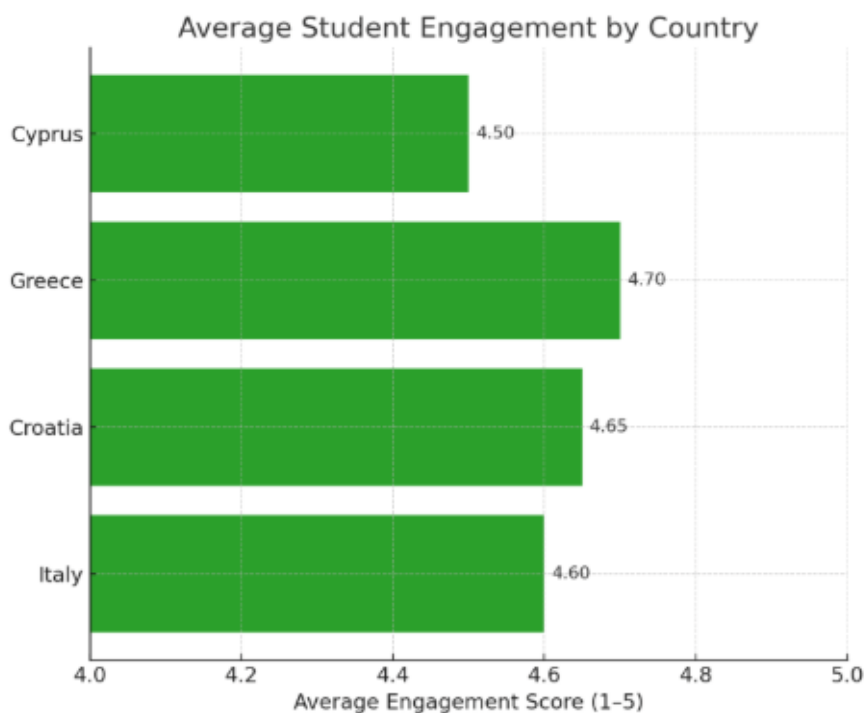


Figure 2. Average Student Engagement Scores by Country in RoboAquaria Pilots

Consultation findings

Stakeholders in Cyprus described RoboAquaria as “a promising educational initiative that successfully combines robotics and environmental science.” Teachers reported that the project strengthened digital literacy, ecological awareness, collabora-

tion, and creativity. Activities such as automating watering, providing immediate feedback to learners. Challenges included limited funding for robotics kits and sensors, a lack of teacher training, and curriculum overload. Equity concerns were also noted, as resource gaps between schools may hinder adoption. Common themes emphasized the importance of linking robotics to real-world environmental issues, providing structured ministry-led training, and fostering stronger school-level coordination.

The consultation in Cyprus produced five interconnected policy themes to support the integration of RoboAquaria into the national education system. First, interdisciplinary robotics modules should be introduced and linked to environmental challenges, with targeted grants ensuring equitable access. Second, primary schools should implement annual project-based environmental modules, supported by a green school certification scheme to promote whole-school sustainability. Third, schools should carry out at least one hands-on STEM project per year, coordinated by a designated STEAM leader to strengthen cross-subject collaboration. Fourth, a national professional development framework should be established, offering tiered certification, mentorship, and technical helpdesks to build teacher capacity and confidence. Finally, a bilingual, open-access STEAM–sustainability framework should be developed and hosted on a national hub, providing consistent, adaptable, and freely available resources for teachers.

Discussion

The findings from the RoboAquaria pilot in Cyprus and across partner countries highlight the potential of integrating educational robotics with marine and environmental education to foster both digital competencies and sustainability values. Consistent with previous research, the high levels of student engagement observed, particularly during hands-on activities, demonstrate that robotics provides an effective platform for experiential and constructivist learning (Eguchi, 2016). The project confirms the role of marine literacy as an essential foundation for pro-environmental behaviors. As UNESCO (2021) and Cava et al. (2005) have argued, embedding ocean-related knowledge within curricula fosters ecological awareness. In the case of RoboAquaria, situating robotics tasks in marine contexts allowed learners to connect technological problem-solving with sustainability challenges, supporting the claim that marine and environmental education can drive positive behavioral intentions.

Challenges and Recommendations

Recurring barriers during implementation included limited classroom time, device malfunctions, shortages of robotics kits, and task complexity for younger learners. To overcome these challenges, the project recommends adopting tiered lesson designs to accommodate diverse student abilities, allocating longer or split sessions for building, testing, and reflection, expanding professional development with troubleshooting resources, ensuring equitable access through one robotics kit per 3–4 learners, pro-

moting structured group roles to balance participation, and embedding short reflection tasks that connect robotics activities to marine sustainability.

Acknowledgements

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Supporting sustainability awareness through Green task design

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Keywords: Sustainability awareness, green task design, prospective mathematics teachers

Abstract

This paper explores how two prospective mathematics teachers, Petros and Alina, engaged students in developing sustainability awareness related to fast fashion industry, through their Green mathematical task designing activity. Drawing on the Heads (academic understanding), Heart (emotional engagement), and Hands (action-oriented activism) framework, the study illustrates the complexity and interdisciplinarity involved in creating Green tasks that balance academic rigor, emotional connection, and activist orientation. Implications are addressed for both the design of Green STEM tasks and the development of STEM teacher educator programs, with particular emphasis on fostering sustainability awareness pedagogical practices.

Introduction

Many studies argue on the ethical and policy necessities to educate the future generations about sustainability (e.g., Gal, 2024). Sustainability entails living within and respecting the ecological boundaries of the Earth. A growing body of research underscores that STEM educators need to foster a generation of environmentally conscious and innovative problem-solvers who can drive sustainable development (e.g., Majeed, & Tahira, 2024). To this end, STEM curricula and professional development programs should equip educators with the skills and strategies to integrate sustainability into their teaching practices (Alsina & Vásquez, 2024). The comprehensive integration of the concept of sustainability into formal STEM curricula is mentioned as *greening of the STEM curriculum* approach (Chesky & Wolfmeyer, 2023). This approach could promote students' *sustainability awareness* which means to empower students to contribute through their actions to a sustainable future. On the other side, researchers emphasize that many common school practices that aim only to improving students' academic outcomes limits students' opportunities to explore broader topics such as sustainability (Li, 2025).

In the field of mathematics education, several studies have emphasized the importance of incorporating mathematics education and sustainable development into teacher professional development programs (e.g., Li, 2025). Salim (2023) identifies the problems that are integrating sustainability issues as *Green tasks*. According to Salim (2023), the central characteristics of designing Green tasks are *authenticity* (use real

data from an existing environmental issue), *complexity* (develop unusual and non-routine mathematical problems), and *projection* (supporting students' awareness to envisage the situation raised by a task). The latter dimension of projection includes raising students' emotions and feelings about environmental phenomena that affect their own lives and also inspire them to take certain actions (ibid).

Designing Green tasks that could foster at the same time STEM inquiry, and sustainability awareness is considered as a complex and challenging activity (Maass et al., 2019). In general, many inherent tensions are central to the decisions must be taken by the task designers, who can be teachers or curriculum developers, in their task designing activity. These tensions would be dilemmas about the degree of task openness, or the aligning the task complexity with the learners' knowledge (Sullivan et al., 2015). The issue of designing Green tasks is more complex since placing Green tasks in the curriculum main aim is to inspire students to take individual actions or press for collective and political actions even after their school completion (Gal, 2024; Li, 2025).

This study lies in the common zone of two different research areas a) designing Green mathematical tasks and b) promoting sustainability awareness in STEM education. The paper explores how two PMTs attempt to support students' awareness of the *environmental impact of fast fashion industry* through their task designing activity. Existing research on how Prospective Mathematics Teachers (PMTs) are designing Green tasks aiming to support students' global awareness is rather limited.

Theoretical framework

The 'Heads,' 'Hearts,' and 'Hands' pedagogical model provides a valuable framework for transformative education by integrating (a) *cognitive and learning dimensions* ('heads'), (b) *affective and emotional dimensions* ('hearts'), and (c) *practical actions* ('hands'). This model has been widely applied to analyze aspects of environmental education (Olsen et al., 2024). Similarly, Wintz et al. (2020) suggest that environmental awareness can be divided into three categories: knowledge and understanding, attitudes and behavior, and participation and action.

Bright and Eames' (2021) explored young people's reported emotions ('heart') regarding climate change—particularly feelings of anxiety—motivated them to deepen their knowledge of the issue ('head') and to take concrete actions ('hands'). Likewise, Gal (2024) examined the feedback of 53 sixth-grade students who participated in an annual educational program on climate change and environmental activism. The findings highlight the school's capacity to foster sustainability awareness by prioritizing the creation of positive and dynamic educational experiences (heart' and 'hands') over a sole focus on comprehension and knowledge acquisition ('head').

Balancing the development of students' academic understanding through problem-solving and modelling activities (Li, 2025) with the promotion of positive engagement and environmental activism (Gal, 2025; Salim, 2023) remains a key challenge for Green STEM task designers.

Methods

The context of the study

The present study took place in the context of the ENSITE project (<https://ensiteproject.eu/>) aiming to enrich prospective STEM teachers' competences in raising students' awareness about environmental issues in their future STEM classrooms. The Teacher Educator selected specific tasks and activities developed in the project and delivered a 10hour PD session in an undergraduate course on "Problem solving in Mathematics classrooms" in a Mathematics Department. Her aim was twofold, to develop prospective mathematics teachers' awareness on environmental issues and to support them to design and enact Green tasks in their future classroom teaching. In this context, PMTs were asked, as part of the course assignment, to design a green task concerning one environmental issue of their choice.

Fifty -eight PMTs worked in groups of two or three and designed 22 Green tasks. Researchers selected 3 Green tasks that outperformed in terms of the task *originality*; *authenticity*; *complexity*; and the *promotion of sustainability awareness*. Then one hour face-to- face semi-structured interviews were conducted with each one of the three PMTs' groups. In the interviews each group of PMTs were asked to: argue on their selection of the specific environmental issue; refer to their inquiry activity while designing the Green task (selection of the specific issue; resources used; decisions taken); their actions in a possible future classroom enactment of the task; as well as their arguments on how they aimed to develop students' awareness. In this paper, we present results based on the analysis of data from one of the three PMTs' groups. Specifically, we focus on a group of two PMTs, Petros and Alina's (pseudonyms), who designed the 'Fast fashion' task. Fast fashion refers to the mass production of low-cost clothing and their quick transporting to retail.

The Fast fashion task scenario

The task requires school students to explore ways to lower the ecological footprint from fast fashion clothing production. The task presented: manufacturing data (fabric expenses and labour costs) from three different countries (USA, China, Pakistan); information about carbon dioxide production in manufacturing garments (jeans) in each of the three countries and information about dioxide production in transporting garments from the China and Pakistan to USA. Some task questions were: *Count all the jeans you have in your closet. How many kilos of carbon dioxide emissions were released in the atmosphere in your jeans' production and transportation from China and Pakistan to USA? Where would you place the factory for the least economic and ecological impact?*

Data and Data analysis

The data used in this paper are a) Petros and Alina's classroom written assignment where they presented the task and its mathematical solutions, the reasons for choosing the specific tasks and the resources used for developing the task and b) The interview data.

The data were analysed according to the ‘Heads’, ‘Hearts’ and ‘Hands’ dimensions in respect to PMTs’ designing activity. The ‘heads’ component referred to how PMTs developed their own intellectual understanding of the fast fashion phenomenon, including its causes and the practical implications of dioxide production in transporting garments all over the world as well as how PMTs transformed this knowledge in their task designing activity. The ‘heart’ component identified on how PMTs supported through their task design activity the cultivation of students’ attitudes, values, and emotional connections as well as the promotion of students’ sense of responsibility towards the fast fashion phenomenon. The ‘hands’ component identified when the task designers promoted students’ engagement in hands-on activities while exploring the practical implications of fast fashion issues.

Results

We present below Petros and Alinas’ arguments in two phases, while they were planning and while they were enacting their designing activity.

Planning the task design activity

Petros and Alina argued about their selection of fast fashion by referring to social, political and ecological characteristics of this issue as follows: “The fast fashion industry is highly polluting, with many factories sourcing cheap raw materials from countries like China and Pakistan, where labor exploitation is common. This task aims to to inform and sensitize students about these issues.”

Thus, PMTs’ rationale was to *develop a task that aimed on raising students’ awareness about the political, social and ecological impacts of fast fashion industries* [‘heart’ or emotional engagement}. During the interview both PMTs admitted that they had a *personal motivation* [‘heart’] in the selection of the specific task. Petros said “[fast fashion] was something we were aware before [the course]”. Alina added “we knew about it from the social media but through this work [the designing activity] we realized that this phenomenon is much more complex than we initially had imagined.”

Petros and Alina, felt the responsibility to *develop their own knowledge* about Fast fashion *by studying relevant academic articles* [such as the Desai et al. (2012) article] relating to the manufacturing and transportation process of retails and the ecological impact of these issues [‘Hands’]. The latter shows the interdisciplinary dimensions of designing Green tasks.

Enacting the task designing activity

The ‘Heads’ component, or the academic dimensions of PMTs designing activity, was evident in certain decisions PMTs made while *making choices on selecting specific authentic data from the academic resources, formulating and (re)formulated the task data in order to make apparent the phenomenon to students’ eyes*. Specifically, they used authentic statistical data from the above academic resources about the labour, manufacturing and transportation costs in different countries. They selected data from two countries that have a massive clothing production (China and Pakistan) and a third

one that most of this production is moving a long distance (USA) to present a clear case on the environmental impact of the fast fashion industry. They argued as follows: Petros “We had data from ten countries, but we choose specific three countries to make clear of the magnitude difference in the numbers [and hence] to argue on the significance of the [fast fashion] problem for the planet”. Aligning data in a way that makes more evident the fast fashion problem in students’ eyes was considered as the most challenging part of their task designing activity Alina: “our main challenge was to decide on which of a big amount of data to select ..we had been working on it for quite a while... it took us almost a month [to complete their task designing activity].” PMTs formulated and reformulated the problem for many times, and they admitted that this was a time-consuming activity.

The ‘Heart’ component, or sensitizing students about fast fashion, was supported by the following PMTs’ actions. PMTs *captured students’ attention by selecting a very common garment for young people* (jeans) and thus, persuading learners that they are part of the fast fashion issue and they could contribute to its solution. Alina: [to students] “the jeans you are wearing maybe is one of these products, so students will realize that they could contribute to the solution by stopping buying from the Fast Fashion industries.” PMTs decided to *simplify the arithmetic data to support all students focus on the sustainability dimensions rather than on the mathematical ones* during their problem-solving process. Alina’s arguments: “we simplified the data so that all students’ main focus to be on the environmental issue [and not on the problem itself]” or “our prime intention is the task to be easily understandable to all students since every one of them could contribute to the solution.” The latter shows that PMTs positioned all students, regardless their abilities and educational needs, as capable contributors to a sustainable future.

The ‘Hands’ dimension was supported a) by *asking students to engage in a decisionmaking* situation on a socio-political issue. Petros’ argument: “Students are tasked with deciding where to locate the factory and weighing the dilemma between maximizing profit and minimizing carbon emissions caused by unnecessary carbon emissions.” b) *by requesting students to take an action against fast fashion industries*. Alina: «...So now that you have the data and you know about carbon dioxide emissions, does your attitude towards recklessly purchasing products from these clothing companies change?”

Discussion

Designing Green STEM tasks, as part of the greening of STEM curricula approach (Chesky, & Wolfmeyer, 2023), is an ethical necessity aiming to foster future generations’ sustainability awareness (Li, 2025). By adapting the ‘hands’, ‘hearts’, ‘hands’ framework (Olsen et al., 2024), this study analyses two PMTs’ actions while planning and enacting the designing of a Green mathematical task on the environmental issue of fast fashion.

In the planning phase, PMTs' sensitivity to the ecological implications of fast fashion ('heart') appeared to motivate their task designing efforts ('hands'), which were directed toward cultivating students' awareness ('heart') and encouraging them to take concrete actions against the fast fashion industry ('hands'). To pursue this objective, the PMTs consulted relevant academic resources and articles to deepen their understanding of the phenomenon, its causes, and its impacts ('head'), which illustrates the interdisciplinary nature of Green task design activity (Maass et al., 2019). In the enacting phase, PMTs developed several actions aligned with the 'head' component. These included selecting and adapting authentic scientific data to formulate and reformulate the problem in ways that engaged and sensitized students ('head'); appealing to students' emotions by focusing on a familiar garment ('heart'); challenging them to make a socio-political decision and encouraging them to take concrete actions against the fast fashion industry ('hands').

This study advances the research on the professional development of prospective STEM teachers by demonstrating that their *active involvement in the design of Green tasks could cultivate their comprehensive understanding of environmental issues* while simultaneously fostering their environmental awareness and activism. Regarding the literature on Green STEM task design, the study offers two principal contributions. First, it underscores the necessity of *integrating academic rigor with students' emotional engagement* as a means of motivating both their individual and collective forms of environmental activism. Second, it highlights *the inclusive dimension of task design*, stressing the importance of positioning all students—irrespective of their abilities or educational needs—as capable and valued contributors to a sustainable future.

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Integrating mathematics and biology teaching: An interdisciplinary STEM approach

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Keywords: interdisciplinary lesson, STEM, mathematics, biology

Abstract

In this paper we describe an interdisciplinary STEM teaching intervention designed and implemented by two teachers of different disciplines (mathematics-biology). We describe the designing and enactment process focusing on the teachers' actions through the lens of activity theory. The activity systems of mathematics and biology teaching had initially different objects but during the implementation phase these objects were interrelated creating a common teaching tools, indicating an interdisciplinary STEM approach.

Introduction

Research demonstrates the benefits for students when they have opportunities to engage with STEM tasks in the school. Furner and Kumar (2007) affirm the importance of integration by pointing out that separating mathematics and science instruction does little to demonstrate the synergistic relationship between math and science as tools for understanding and making sense of the real world. We see interdisciplinary definition as "knowledge and modes of thinking from two or more disciplines are integrated to produce a cognitive advancement that would have been impossible or unlikely through single disciplinary means. In this study we see through the lens of activity theory (Engestrom,1987), a two-hour interdisciplinary lesson that was designed and enacted in an 11 grade classroom (24 students separated in 5 teams), by two teachers (mathematics and biology) after they had participated in the ICSE Workshop series (<https://icse.eu/icse-academy/>). In this study we try to shed light into the process of designing and implementing an interdisciplinary task integrating mathematics and biology.

The designing of the interdisciplinary lesson

The task was designed by the two teachers and combined both concepts and processes from mathematics and biology such as: size, surface area and volume integrating the function of an organ and the needs of an organism. As we analyzed the designing phase, we saw 2 activity systems separate from each other. The one of mathematics teaching consists of a preparation phase referring to the key mathematics idea

needed in order to formulate the mathematical expected model for the biological problem that appears in the next section of the lesson. The questions in the worksheet were about *“what will happen to the surface area of a square if we enlarge or reduce it by 10 times and then n times; what will happen to the volume of a body if we enlarge it by m times”*. In the biology activity system, we see in the design a set of questions about a fictional character Ant-Man (Avengers, the movie) aiming to engage the students in order to speculate what effect the size change would have on this character: *“what would happen to Ant-Man if he shrunk at a size of an ant when he is taking a shower or increases up to 20 meters?”*. Afterwards the design of the task is referring to biological aspects of the morphology of human respiratory and digestive organs in comparison to those of the earthworms; *“The earthworm breaths through its skin and has a linear intestine for the digestion of its food. Compare it with the corresponding human organs. Can you explain why such differences exist?”*. We analysed the different activity systems and saw that the goals (objects) seemed to be separated at first. Mathematics teacher says: *“I can see the mathematics behind some aspects of the real world...but, in biology what mathematics do they use? ...”* Biology teacher: *“if I was alone, I wouldn’t see the mathematical concepts that was relevant here...it is more complicated in real biology...but I want to give students the opportunity to make such connections...”*

The implementation of the interdisciplinary lesson

During the implementation of the task the mathematics teacher engaged students in mathematical inquiry in order to create the mathematical key idea (mathematics-object) needed for the biological part. We analyzed teachers’ actions and the tools they used in order to accomplish their goals (Table 1).

Table 1

Teachers’ actions and tools

Phase	Teachers’ actions	Tools
Preparation	In this phase the inquiry was about the mathematics phase / needed in order to formulate the mathematical expected inquiry in model for the biological problem presented in the next mathematics section of the lesson. The mathematical questions addressed to measurement of surface and volume. The students worked with the key mathematical idea relevant to the biological problem afterwards. They use a balloon in order to see the generalization of the raise of the surface and volume when we maximize an object in 3 dimensions.	Paper, pencil and worksheet Balloon, marker

Integration The teachers gave the students instructions to seek information about the respiration system of humans and the difference from worms. The students responded but **biology** seemed to have difficulties to explain or find connections with the mathematical model. The mathematics teacher takes a leading role and gives measures of the worm in question.

Tablet, worksheet

To prepare students to simulate a body organ (transfer from 2-D to 3-D as in the real world) teachers decided to use a balloon and some markers asking them to draw some squares and then inflate it: “*what happens to the squares in the surface area of the balloon?*”. After this part the teachers realized that time wasn’t enough for the whole designed biological inquiry (biology-object) so, they decided to skip the part with the Ant-man: “*we had no time for all the questions, the inquiry phase in biology was about find themselves some information using the tablets...*”. The students responded about the differences between worm and human organs (*the worm respire from its skin, the human lungs have 70m² area surface...*) but, they found difficulties in justifying their ideas or find connections with the mathematical model, so the mathematics teacher interferes in the biology activity system and gives measures of the worm in question: “*what if the worm was 2mm and enlarges to 2m, how many times multiplies its surface? You have to make an argument here...*”. So, we have two activity systems: mathematics teaching and biology teaching that integrate in order the students to understand the connection between the biology phenomenon of the morphology of the human body organs and the differences among other organisms. Analyzing the implementation of the task we see that the actions of the teachers interacted in creating sharing objects, their cooperation in designing highlights their creativity that led to the creation of common didactical tools- the balloon as a model of a 3-D organ and Ant-man as a scaffolding idea (it’s a fiction super hero!) of enlarging and reducing an organism. Summing up, although collaborative design and implementation of an interdisciplinary task has its constraints e.g. time consumption, separate curriculum, different epistemological and teaching approaches between mathematics (emphasis on mathematics procedure and not in modelling and problem solving) and biology (emphasis on scientific inquiry treating mathematics as a tool) is also a vehicle of promoting integration of mathematics and science.

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From Creative Thinking to Sustainable Solutions: Transforming STEM Classrooms through the Innovative FOCUS program

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Abstract

The Innovative FOCUS program, developed at the University of Education Upper Austria, integrates scientific creativity into STEM education to support Education for Sustainability (EfS). It consists of two components: Scientific Creativity in Practice (SCIP) and the InFOCUS Challenge. This paper focuses on SCIP and one of its core tools, Thinkflex, encourages students to approach problems flexibly, explore multiple perspectives, and generate diverse, original solutions. To evaluate the program's impact, a two-group, repeated-measures study was conducted in Austrian secondary schools. Twenty-six classes received SCIP tools, while twelve control classes followed traditional methods. Students' divergent problem-solving abilities were assessed with the Divergent ProblemSolving Ability in Science test (DPAS) at the beginning and end of the school year. Data were analyzed using multilevel modeling and structural equation modeling. In addition, 35 teachers participated in a one-year training program and provided feedback on SCIP through questionnaires. Results showed that students in the SCIP group demonstrated significantly stronger gains in divergent thinking compared to the control group, even with a moderate number of interventions. Teacher evaluations confirmed the program's practicality and effectiveness. These findings highlight SCIP as a scalable and adaptable approach to fostering scientific creativity within STEM classrooms. By linking creativity with sustainability-oriented education, SCIP equips students with essential competencies for addressing complex global challenges.

Introduction

Education for Sustainability (EfS) represents a transformative educational approach that equips learners with the knowledge, skills, values, and competencies necessary to shape a sustainable future (Unesco, 2020). This comprehensive framework encompasses multiple interconnected elements that work together to address the complex sustainability challenges outlined in the United Nations' Sustainable Development Goals (SDGs). Especially the promotion of scientific creativity plays an important role in EfS (Sandri, 2013).

Therefore, at the University of Education Upper Austria the Innovative FOCUS program was developed to integrate scientific creativity and EfS into STEM education

(Haim & Aschauer, 2024). The Innovative FOCUS program comprises two sub-programs, Scientific Creativity in Practice (SCIP, Haim & Aschauer, 2022) and InFOCUS Challenge (Haim & Aschauer 2024). SCIP was developed specifically for STEM teaching and is presented in more detail in this article. The InFOCUS Challenge builds on the SCIP program but is primarily designed for project-oriented teaching by tackling real-world sustainability challenges.

Theoretical Framework

Education for Sustainability

Education for Sustainability (EfS) is a transformative approach to learning that equips individuals and communities with the knowledge, values, skills, and motivation needed to shape a more just, inclusive, and sustainable world (Rieckmann et al., 2017). Its central aim is not only to inform but also to empower learners to act responsibly in the face of global challenges such as climate change, biodiversity loss, resource scarcity, and social inequality (Unesco, 2020). Several core elements and principles underpin EfS (Wiek et al., 2011; Rieckmann, 2012; Glavič, 2020).

One of the main principles of EfS is its holistic and future-orientated perspective (Ryan, 2012). Sustainability challenges cut across disciplines such as economics, ecology, politics, and culture. Therefore, education for sustainability integrates multiple perspectives and encourages systems thinking (Wiek et al., 2011).

In addition to different pedagogical principles (Rieckmann et al., 2017), the EfS concept also encompasses specific competencies (deHaan, 2010), like critical and creative thinking (Straková & Cimermanová, 2018; Sandri, 2013; Shu et al., 2020). Learners are encouraged to question assumptions, analyze power structures, and explore alternative solutions to sustainability problems. Equally important is creativity, as innovative thinking is essential for designing sustainable technologies, lifestyles, and social systems. Therefore, scientific creativity serves as a fundamental catalyst for education for sustainability, representing the essential cognitive capacity to generate novel, useful solutions to complex environmental challenges.

Scientific Creativity

The concept of scientific creativity, shaped largely by Guilford and Torrance, can be understood as a form of creativity specific to science that combines both general and subject-related competencies (Hadzigeorgiou et al., 2012; Hu & Adey, 2002). Domain-specific competencies are rooted in subject knowledge. Creative contributions in science often emerge by varying or recombining existing knowledge into new patterns (Benedek & Fink, 2019). This means that understanding scientific concepts, grasping their interconnections, and possessing relevant skills—such as formulating or testing hypotheses—are essential foundations for creativity (Huang et al., 2017). General creativity competencies, on the other hand, involve broader cognitive abilities. These include divergent thinking, making associations, analogical reasoning, imagination, and metacognitive awareness (van de Kamp et al., 2015; Hadzigeorgiou et

al., 2012; Hu & Adey, 2002; Kind & Kind, 2007). In scientific creativity, divergent thinking is seen as a key indicator of creative problem-solving (Huang et al., 2017) and involves fluency (number of ideas generated), flexibility (variety of categories those ideas fall into) and originality (uniqueness or unexpectedness of ideas). Both convergent and divergent thinking are essential for creativity: convergent thinking supports knowledge generation, while divergent thinking enables the recombination of ideas in new ways.

The SCIP program

Scientific creativity comprises several creative skills and metacognition. Therefore, the SCIP program includes a variety of tools to foster individual creativity competences in STEM lessons (Haim & Aschauer, 2024). One of these tools, called Thinkflex, is of particular importance for EfS and is therefore described in more detail below.

THINKFLEX CHALLENGE Electric Light

I. Problem Finding

Problem Statement
We all use electric light in our everyday lives and consider it to be very useful. Nevertheless, the use of electric light also has disadvantages and problems arise. Name as many problems as possible that arise from the use of electric light.

1. Capture the Problem
Do you know all the terms and do you understand the task?
Clarify any outstanding issues with the teacher.

2. Brainstorming
Imagine the situation, a sketch can be helpful.
Think in all directions, the PERSPECTIVE CHECK can help you!
Note your ideas in the table.

What problems do you find?

3. Exchange
Form small groups and present the problems to each other.
Think about other ideas in the group and write them down.

4. Presentation & Discussion
Present your problems to the class and discuss them.
Create a collection of selected problems together and cluster them.

PERSPECTIVE CHECK
Look at the topic from different perspectives.

Sensory impression

People or age groups

Times

Plants or animals

Place or point of view

Advantages or disadvantages

II. Problem Solving

Problem Statement
Now develop creative solutions to overcome or reduce the problems of a category caused by the use of electric light.

5. Brainstorming
In small groups, choose a category from the cluster.
Our selected category:

Find many different solutions to the problems from the category.
Think in all directions, the PERSPECTIVE CHECK can help you!
Note your proposed solutions in the table.

What creative solutions do you find?

6. Presentation & Discussion
Present your three best ideas to the class.
Discuss the ideas according to the criteria of originality, feasibility and effectiveness.

PERSPECTIVE CHECK
Look at the topic from different perspectives.

Sensory impression

People or age groups

Times

Plants or animals

Place or point of view

Advantages or disadvantages

Figure 1. Example of a Thinkflex Challenge Worksheet

The term Thinkflex combines the words think and flexibility, highlighting its purpose. Students should tackle problems in flexible and adaptable ways. It invites learners to broaden their thinking, exploring possibilities in multiple directions rather than sticking to a single path. To achieve this, tasks should be approached from different perspectives, ensuring a rich diversity of ideas. To support students in this, we have developed a so-called perspective check, which is embedded in each worksheet (see Figure 1).

In Figure 1 one special type of Thinkflex is presented. This type is called Thinkflex Challenge.

The first part is about problem finding. Learners are given an actuality and are then asked to think of as many different problems as possible that are related to this

actuality. 3. Exchange: In a third step (called Exchange) the pupils present and discuss their ideas within a small group. In addition, they also think about other possible answers within the group. At the end, the learners present their group results to the whole class and a joint collection of ideas should be created.

The second part is about problem solving. In small groups they should develop creative solutions to overcome or reduce the problems they found in the first part, at least the problems of one category. Finally, the groups present their three best ideas to the class and discuss the ideas according to the criteria of originality, feasibility and effectiveness.

Methods

A research project (Haim et al., 2024) investigated how the SCIP program influences students' scientific creativity, specifically their divergent problem-solving abilities in science. The research employed a two-group, repeated-measures design in Austrian secondary schools. In total, 26 classes received instruction through teaching strategies based on the SCI program, while 12 classes served as a control group and continued with conventional methods. To evaluate the program's impact, the Divergent Problem-Solving Ability in Science test (DPAS) was administered both at the start and the end of the school year. Since the SCIP activities were implemented at the class level, the analysis made use of multilevel modeling in Mplus 8.1. In addition, the outcome variable—divergent problemsolving ability—was treated as a latent construct. This justified the use of structural equation modeling, which makes it possible to integrate both the measurement model and the structural model (e.g., the effects of SCIP). For more details see Haim et al. (2024).

For an intervention to be implemented with fidelity, adequate training and supervision by interventionists during the intervention study are required (Gearing et al., 2011). For this reason, a one-year in-service teacher-training program have been offered. The training program is structured into alternating input, implementation, and reflection phases. In the input phases, both the theoretical concepts of scientific creativity are discussed and the individual SCIP techniques were introduced. In the implementation phases, the teachers apply the SCIP techniques in their own lessons. As part of the training, teachers (N = 43) were asked to assess the SCIP techniques. Therefore, an online questionnaire was administered to the teachers at the end of the teacher training program. They rated the effectiveness of each tool on a 5-point Likert scale (from “very low” (1) to “very high” (5)).

Results

SCIP-Students showed a statistically significant increase in divergent thinking ability compared to control groups. Even with an average of 10 interventions per year, the effects were robust, suggesting that successful implementation does not require a radical change of teaching.

During the teacher-training program all teachers reported that the SCIP tools proved to be very efficient and well implementable. This is also confirmed by the results of the survey, in which teachers rated the effectiveness of each SCIP tool on a 5-point Likert scale (from “very low” (1) to “very high” (5)). All techniques were rated positively. For example, Thinkflex was rated 4.53 (SD= 0.69) on average.

Discussion

The findings provide evidence that SCIP effectively fosters scientific creativity, particularly divergent thinking and metacognition. The SCIP program can be integrated into regular teaching with relatively minor adjustments, making them accessible and scalable. Scientific creativity will play an increasingly important role in science education, especially in the context of EfS. The SCIP program, thus, may play a significant role in enhancing scientific creativity and EfS. However, the contribution of SCIP tools to EfS needs to be examined more empirically in the future.

For more information about SCIP see: www.school-creative-solutions.at

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From Creativity to Sustainability: Empowering STEM Education through the Innovative FOCUS Program

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Abstract

Global challenges such as biodiversity loss, climate change, and resource scarcity require innovative, interdisciplinary solutions. Yet schools often leave students overwhelmed: they learn about problems but rarely acquire the tools to act on them. This article introduces the Innovative FOCUS (InFOCUS) program, developed at the University of Education Upper Austria, as a model for embedding creativity, sustainability, and entrepreneurship into STEM education. Building on the Scientific Creativity in Practice (SCIP) program, which develops divergent thinking and creative personality traits through domain-specific STEM tools, InFOCUS extends these principles into sustainability-focused, challenge-based learning. The program follows a two-step structure: (1) implementation of creativity tools in STEM lessons; and (2) project-oriented learning in which student teams address real-world challenges linked to the United Nations Sustainable Development Goals (SDGs). Empirical evidence from 19 teachers and 270 students across 19 Austrian schools demonstrates high feasibility and strong outcomes: 62 of 64 student teams successfully developed sustainability prototypes, teachers rated the tools highly, and students reported high levels of interest, enjoyment, collaboration, and entrepreneurial thinking. The InFOCUS program offers a scalable and interdisciplinary framework that empowers students to become changemakers capable of shaping sustainable futures.

Introduction

The 21st century confronts young people with profound challenges. Over the past five decades, global biodiversity has declined by nearly 75% (WWF, 2022). Students are acutely aware of these crises, yet many respond with paralysis or denial—either perceiving themselves as the 'last generation' or disengaging from the problems altogether.

What is needed are changemakers—students who can identify problems, think innovatively, collaborate effectively, and implement sustainable solutions (Drayton, 2006).

The Innovative FOCUS program was designed to cultivate these competencies by embedding creativity and sustainability into STEM education. The program bridges creativity research, education for sustainable development (ESD), and entrepreneurship

education, offering teachers a structured yet adaptable model for transformative STEM teaching.

Theoretical Framework / Literature Review

Scientific Creativity: The foundation of InFOCUS lies in the concept of scientific creativity, which emphasizes the ability to generate original ideas and solutions within scientific domains. Hu and Adey (2002) defined scientific creativity as involving flexibility, fluency, and originality—skills particularly critical in STEM problem-solving. Later work emphasized the role of analogical reasoning, divergent thinking, and creative experimentation in science education (Hadzigeorgiou et al., 2012).

Education for Sustainable Development (ESD): Addressing global challenges requires competencies beyond content knowledge. Wiek et al. (2011) identified key sustainability competencies, including systems thinking, anticipatory skills, and strategic action. Rieckmann et al. (2017) further emphasized the need for pedagogical approaches that empower learners to engage in transformative action.

Entrepreneurship and Transformative Learning: Entrepreneurship education contributes tools for translating creative ideas into real-world impact. Lindner (2018) argued that entrepreneurship education should prepare learners for a sustainable future, while Malmqvist et al. (2015) highlighted the role of challenge-based learning in fostering innovation. InFOCUS operationalizes these perspectives by merging scientific creativity with sustainability competencies and entrepreneurial thinking.

The FOCUS Framework: The acronym FOCUS stands for Flexibility, Originality, Creative Personality, Unconscious Mind, and Strategy. It encompasses the skills needed for students to act as changemakers. Collectively, these elements provide a practical foundation for integrating creativity, sustainability, and innovation in STEM classrooms (Haim & Aschauer, 2024; Haim & Aschauer, 2022).

Methods

Participants and Context: The program was piloted in Austria between 2021 and 2022. A total of 19 secondary school teachers participated, implementing InFOCUS with 270 students across 19 schools. Students formed 60 project teams.

Intervention Design: InFOCUS follows a two-phase model (see Fig.1).

Step I – Scientific Creativity in Practice (SCIP)	Step II – InFOCUS Challenge
Implemented in STEM lessons • Thinkflex • Flexperiments • WOSECO • Shorty & Flexy	Project-oriented lessons with SDG challenges • Design Thinking • Embodiment & mindfulness • Inner Development Goals • Mission: Possible card set

Focus: Divergent thinking, originality, creative personality traits	Focus: Team collaboration, prototyping, sustainability solutions
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Figure 1. Two-step structure of the Innovative FOCUS program

Step I – Scientific Creativity in Practice (SCIP): Implemented in STEM lessons. Students engaged with tools such as Thinkflex (divergent thinking), Flexperiments (creative experimentation), WOSECO (word associations), and Shorty & Flexy (metacognition and resilience). All tools of the SCIP program are described in more detail in Haim and Aschauer (2022).

Step II – InFOCUS Challenge: Implemented in project-based lessons. Student teams selected sustainability challenges from a curated 'challenge pool' linked to the SDGs (e.g., mobility, food waste, biodiversity). They applied creativity techniques, embodied and mindfulness practices, and innovation strategies such as Design Thinking to design and pitch prototypes. Teachers used the Mission: Possible card set, containing nearly 50 tools, to scaffold the innovation process.

Data Collection: Data included teacher training evaluations, student self-reports using the Intrinsic Motivation Inventory (IMI), classroom observations, and prototype completion rates.

Practical Tools and Card Sets for Creative Project Work: The FOCUS Program provides a variety of creativity tools and card sets that support different stages of project work. They offer educators and students practical methods to stimulate ideas, structure processes, and reflect on outcomes. All tools used in the program are part of the FOCUS card set, which also contains additional methods. Figure 2 shows one of the cards, including both front and back sides, as an example.

The card set is designed to support teachers in preparing project phases with their classes. At the same time, the cards can be used directly in the classroom as facilitation material to guide group processes and stimulate creative dialogue. Figure 2 below describes a selected tool from the card set in more detail.

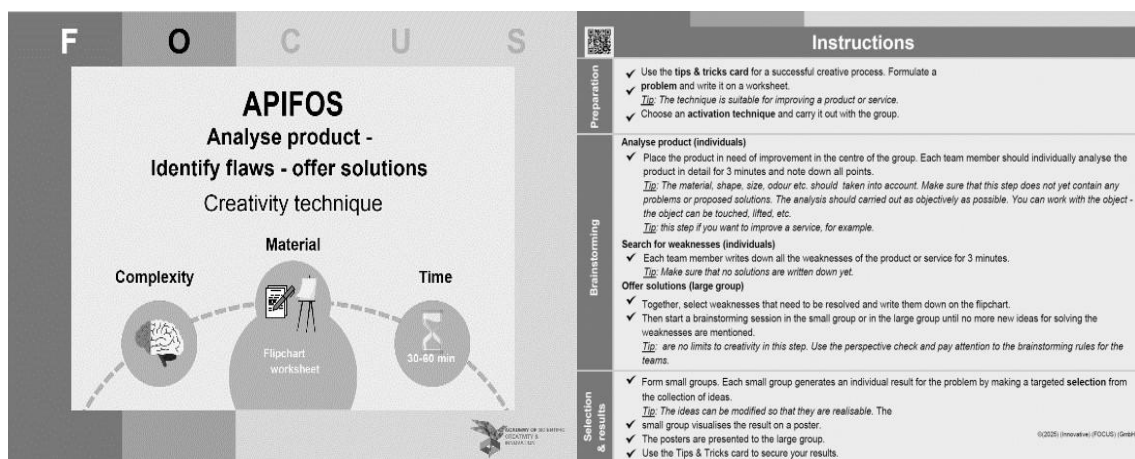


Figure 2. Example of a card from the InFOCUS card set of the APIFOS method (Analyse Produkt – Identify Flaws – Offer Solutions).

Results

Student Outcomes: 62 out of 64 student teams (97%) successfully developed prototypes addressing real-world sustainability challenges. IMI data showed high levels of student interest/enjoyment ($M \approx 4.4/5$) and perceived competence. Students reported increased collaboration and entrepreneurial thinking.

Teacher Outcomes: Teachers rated tools as highly applicable. For example, Thinkflex received a mean rating of 4.14/5, and APIFOS 4.07/5 (Haim & Aschauer, 2024). Teachers highlighted that the program was feasible to integrate within standard curricula, requiring approximately 5–6 lessons to teach core techniques and ~30 lessons for project work. The results are summarized in Table 1 below.

Table 1

Outcomes of the Innovative FOCUS Program

Criterion	Findings	Notes
Prototype completion	62 of 64 teams (97%)	Mobility, waste reduction, biodiversity
Student motivation	High (IMI $\sim 4.4/5$)	Interest, enjoyment, collaboration
Teacher ratings	Thinkflex 4.14/5 APIFOS 4.07/5	Feasible across school types

Scalability: The program proved effective across diverse school types, suggesting transferability to different contexts. Its modular structure allowed teachers to adapt tools and project scope according to local conditions.

Discussion

The findings suggest that InFOCUS successfully integrates scientific creativity, sustainability, and entrepreneurship into STEM education. By combining creativity tools with SDG-oriented challenges, the program enables students to move from problem recognition to solution implementation.

Educational Significance: For students, InFOCUS fosters innovation competencies, teamwork, resilience, and entrepreneurial mindsets. For teachers, it provides a practical toolkit that does not overburden instruction while enriching STEM learning. For systems, it offers a scalable and policy-relevant model. In Austria, InFOCUS aligns with curricular reforms (e.g., the new subject Wirtschaft, Innovation, Nachhaltigkeit [WIN]) and elective modules such as the Changemaker Lab (Haim, 2025).

Limitations and Future Directions: While prototype development served as a useful proxy for student innovation, long-term impacts on career pathways and sustainability behaviors remain to be studied. Future research will examine neural correlates of creativity through collaborations with Penn State University (fNIRS studies) and explore

the potential of AI-supported online training platforms. The emerging international “School of Creative Solutions” network will support cross-cultural adaptation and scaling.

Note: Selected worksheets on the InFOCUS tools can be downloaded from the homepage www.school-creative-solutions.at or requested from the authors.

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Our society faces enormous challenges that require innovative and sustainable solutions. Among the most pressing issues for education today are diversity in STEM education, digitalisation, interdisciplinarity, and sustainability. Addressing these issues in STEM education, helps preparing young people to become active, responsible citizens. Teachers are central to this transformation, and their professional development is crucial for fostering competences that matter in the 21st century.

Educating the Educators (ETE) is an international conference series on professional development in STEM education that brings together teacher educators, policy makers, teachers and other stakeholders. The fifth edition, ETE V, marked the celebratory finale of the ICSE Academy project and focused on teacher mobility as a driver for innovation in STEM education. Participants explored how mobility experiences can strengthen inclusion, sustainability and digitalisation in teaching and learning, and how systemic structures can support these efforts.

ETE V provided a vibrant space for exchange, collaboration and co-creation, highlighting the importance of shared practices and policies for scaling up innovative approaches in STEM teacher education. This volume reflects the main themes and discussions of the conference and the collective vision for future collaboration.



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