

Operationalizing Science, Technology, Engineering, and Mathematics Teacher Education through the AcaSTEMy Project

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ABSTRACT

The Erasmus+ acaSTEMy Teacher Academy project seeks to operationalize a future-oriented approach to Science, Technology, Engineering, and Mathematics (STEM) teacher education that connects disciplinary learning with authentic societal challenges. This conceptual paper synthesizes research-informed principles underpinning the project and explains how they are translated into teacher professional learning. The framework positions integrated STEM education as problem-centered learning that combines scientific inquiry, engineering design, mathematical reasoning, digital technologies, and responsible societal decision-making. It brings together transversal and transformative competences, sustainability education, systems thinking, digital confidence, strategic thinking, and career awareness within a three-stage model that moves from socio-scientific relevance through inquiry and conceptual learning to reflection and evidence-informed action. These principles are operationalized through teacher-education modules, micro-credentials, job shadowing, mobility, and professional-learning networks. The paper argues that the main contribution of the acaSTEMy project lies not in proposing a single universal teaching model but in providing a coherent and adaptable framework for translating contemporary STEM-education priorities into teacher development and classroom practice across diverse European contexts. It also identifies implementation challenges related to disciplinary traditions, resources, institutional capacity, and the need for longer-term evaluation.

KEY WORDS: Integrated science, technology, engineering, and mathematics education, sustainability education, systems thinking, teacher professional development, transversal competences

INTRODUCTION

The Erasmus+ acaSTEMy project is a European Science, Technology, Engineering, and Mathematics (STEM) teacher-education initiative that seeks to strengthen the quality, relevance, and future orientation of STEM teaching and teacher learning. It seeks to promote teaching skills and competences, sustainability education, digital confidence, and innovative professional development for teachers and teacher educators through a STEM-oriented approach to science education.

STEM education is understood as an integrated, problem-oriented approach in which learners draw on knowledge and practices from STEM to investigate authentic real-world problems while designing and evaluating practical solutions. It therefore connects disciplinary knowledge with inquiry, engineering design, digital technologies and societal challenges, including sustainability and the development of future-oriented competences (Kelley and Knowles, 2016; National Research Council, 2012; National Academy of Engineering and National Research Council, 2014; OECD, 2019; Redecker, 2017; Thibaut et al., 2018; UNESCO, 2017).

In the acaSTEMy project, STEM education is promoted to investigate authentic real-world problems and design and evaluate practical solutions (Kelley and Knowles, 2016; Moore et al., 2014). Within this approach, curricular integration is operationalized across two distinct modalities: Interdisciplinary integration, which explicitly preserves individual subject boundaries while intentionally mapping explicit connections, concepts, and cross-cutting practices between them, and transdisciplinary integration, which transcends traditional disciplinary silos altogether by organizing the entire learning experience around a real-world problem or socio-scientific issue and drawing on relevant subject knowledge, as required by the context (National Research Council [NRC], 2014).

Within the project, promoting these priorities means embedding them in teacher education, continuing professional development (CPD), classroom materials, mobility activities, and micro-credential courses. Operationalizing them means translating the priorities into practical structures, including digital-skills materials, teaching and learning modules, mobility formats, job shadowing, and micro-credentials (AcaSTEMy consortium, D4.1).

CONCEPTUALIZING STEM WITHIN SCIENCE EDUCATION

STEM can be conceptualized as encompassing a range of relationships among STEM and therefore serves as an umbrella term whose interpretation depends on the educational purpose and context. Recent literature continues to emphasize that there is no single universally accepted conceptualization of STEM education and that important distinctions need to be made between disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary approaches (Gao et al., 2020; Reynante et al., 2020; Roehrig et al., 2021; McLure et al., 2022).

At one end of this range, STEM may simply refer collectively to STEM while the individual disciplines continue to be taught independently. In multidisciplinary STEM, the disciplines address a shared topic, context, or problem but largely retain their distinct disciplinary knowledge, methods, practices, and learning outcomes. In interdisciplinary or integrated STEM, disciplinary boundaries are deliberately crossed, and meaningful connections between two or more STEM disciplines become part of the learning process. Students may, for example, draw simultaneously on scientific explanations, mathematical modeling, engineering design, data analysis, and technological tools within a single investigation or problem-solving activity (Gao et al., 2020; Reynante et al., 2020; Roehrig et al., 2021).

Where learning is organized around an authentic societal, environmental, or technological problem rather than around individual school subjects, STEM may take on a transdisciplinary orientation. Here, the problem itself becomes the organizing focus, and learners draw on whatever disciplinary knowledge and practices are necessary to understand the problem, develop possible solutions, and evaluate their consequences. Even where learning begins with disciplinary science knowledge, broader social, environmental, ethical, and technological considerations may therefore become important in evaluating potential solutions (Gao et al., 2020; Roehrig et al., 2021; McLure et al., 2022). At the same time, STEM education is also associated internationally with wider policy objectives, including technological innovation, economic competitiveness, preparation for STEM-related careers, strengthening national scientific capacity, and developing the STEM literacy needed for informed participation in society (Roehrig et al., 2021).

Within the acaSTEMy project, STEM is best understood as a progression from disciplinary science taught under a collective STEM label toward genuinely integrated, problem-centered learning. This interpretation is consistent with recent frameworks in which high-quality integrated STEM is characterized by authentic or real-world problems, meaningful disciplinary integration, inquiry and engineering design, engagement in STEM practices, collaboration, and links with future STEM participation and careers (Roehrig et al., 2021; McLure et al., 2022; Le et al., 2023).

In science classrooms, integrated STEM can be organized around scientific inquiry and engineering design. Students investigate phenomena, formulate questions, construct and evaluate scientific explanations, define problems, develop and test possible solutions, analyze quantitative evidence, use models, and iteratively improve designs or products. Science provides explanatory and conceptual knowledge; engineering frequently provides the design and problem-solving context; mathematics supports measurement, modeling, analysis, and representation; while technology provides both tools and practical means for generating, testing, and communicating solutions. Importantly, integration should not simply place several STEM activities alongside one another. Connections among disciplinary concepts and practices need to be intentional and made visible to learners (Reynante et al., 2020; Roehrig et al., 2021; McLure et al., 2022). Thus, the educational value of STEM does not arise simply from labeling an activity as “integrated;” rather, it depends on purposeful integration of disciplinary knowledge, practices, context, and learning goals.

Of particular importance within the acaSTEMy project approach is that relevance provides the starting point for learning. Students encounter problems and phenomena that have meaning beyond the immediate acquisition of subject content. They select and use appropriate tools and technologies, undertake inquiry, develop scientific and engineering practices, construct and apply conceptual knowledge, and engage in reflection on the societal uses, implications, and consequences of science and technology. Research on integrated STEM increasingly emphasizes authentic problems that connect with learners’ experiences and contexts, rather than decontextualized activities in which integration is largely implicit (Roehrig et al., 2021; McLure et al., 2022).

This learning process is intended to develop not only conceptual knowledge, practical and reasoning skills, but also attitudes, values, agency, STEM-related aspirations, and identity. Contemporary research treats STEM or science identity as an important educational outcome because students’ perceptions of their competence, performance, interest, and recognition as a “science/STEM person” are associated with engagement, persistence, and future educational and career intentions (Chen and Wei, 2022; Dou and Cian, 2022). Participation in authentic scientific practices can itself contribute to the development of motivation and STEM identity (Starr et al., 2020). Thus, career awareness and STEM identity should not be viewed as outcomes separate from classroom learning, but as dimensions that can develop through meaningful participation in STEM practices.

At the same time, the goals of STEM education extend beyond preparing future scientists and engineers. Science and STEM education have an important role in preparing learners to engage with socio-scientific problems, consider evidence alongside ethical and societal dimensions, and participate responsibly in decision-making. Recent work on science

education for responsible citizenship similarly emphasizes relevance, socio-scientific issues, argumentation, values, and the relationship between science and society (Evagorou et al., 2020). This dimension is especially important when STEM learning addresses sustainability, environmental challenges, health, technological change, or other complex problems whose solutions cannot be evaluated through technical criteria alone.

The acaSTEMy project approach therefore seeks to integrate disciplinary core ideas, crosscutting concepts, and scientific and engineering practices, building on the framework presented in *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2012). These practices include asking questions and defining problems, planning and undertaking investigations, developing and using models, using appropriate tools, analyzing and interpreting data, constructing explanations and designing solutions, engaging in argument from evidence, and communicating information.

Contemporary analyses of integrated STEM similarly identify investigating, modeling, working with data, using tools, solving problems, evaluating ideas and solutions, and communicating as practices that can provide productive links across STEM disciplines (Reynante et al., 2020). STEM practice therefore involves substantially more than manipulating apparatus or completing a prescribed practical activity.

This contemporary perspective also extends the argument made by Holbrook and Rannikmäe (2009) that science education should move beyond the acquisition of decontextualized scientific content toward the development of scientific and technological literacy. Such literacy encompasses relevance, intellectual development, communication, attitudes and values, and responsible participation in society. In this sense, recent integrated-STEM research does not replace this earlier orientation but strengthens it by explicitly connecting relevance and scientific literacy with interdisciplinary problem solving, engineering design, STEM practices, identity, and career awareness.

The resulting acaSTEMy project model can therefore be conceptualized as a context-based, iterative educational process. Learners engage with authentic scientific, technological, environmental, and societal problems; identify and evaluate appropriate knowledge, tools, materials, and technologies; plan and undertake investigations; generate, analyze, and interpret evidence; construct explanations; and design and evaluate possible solutions. Through modeling, argumentation, communication, collaboration, and reflection, they connect practical experiences with disciplinary conceptual knowledge and interdisciplinary understanding. Over time, such experiences are intended to promote conceptual understanding, practical and reasoning skills, higher-order thinking, critical attitudes and values, technological literacy, STEM identity, career awareness, and the capacity for informed and responsible participation in society.

This paper outlines the theoretical and empirical support for key pedagogical components proposed in STEM and science education frameworks. It integrates foundational literature spanning context-based learning, inquiry, scientific practices, philosophy of technology, and scientific literacy. Table 1 seeks to sequence the proposed pedagogical components.

CORE CONCEPTUAL AREAS WITHIN THE ACASTEMY PROJECT

Transversal Skills and Competences

Promoting transversal skills in the acaSTEMy project means embedding transferable abilities – including communication, collaboration, critical thinking, creativity, problem-solving, adaptability, digital literacy, and cultural awareness – within meaningful STEM teacher education and learning activities. In line with the OECD (2019), the broader aim is to help learners apply STEM knowledge, collaborate, think critically, and act responsibly in real-world situations.

Sustainability Education

Within the acaSTEMy project, sustainability education is understood as an approach to teaching and learning that equips individuals with the knowledge, skills, attitudes, and values needed to contribute to an environmentally responsible, socially equitable, and economically viable future. It extends beyond adding environmental topics to the curriculum. Learners should be able to:

1. Understand the interdependence of ecological, social, and economic systems
2. Think critically about present and future challenges
3. Participate in informed decision-making.

The project supports STEM teachers in integrating climate action, resource use, health and well-being, the European Green Deal, and education for sustainable development into classroom practice. The aim is to help learners understand real-world environmental and social challenges and recognize their capacity to contribute to sustainable futures (acaSTEMy Consortium, 2024; Bianchi et al., 2022; Council of the European Union, 2022, UNESCO, 2017).

Systems Thinking

Systems thinking within the acaSTEMy project is seen as a holistic approach to understanding complex environments by examining how interconnected parts interact to produce emergent behaviors. It highlights feedback loops, non-linear effects, delayed outcomes, and unintended consequences, while recognizing that perspectives, system boundaries, and underlying assumptions influence how problems are understood. By focusing on relationships and the whole system rather than isolated elements, it helps identify effective leverage points for lasting change.

In the acaSTEMy project, systems thinking is both a teacher-training topic and an organizing principle. Teachers learn to use systems and concept mapping to help students explore links between scientific, environmental, economic, and human

Table 1: Evidence matrix for proposed educational components

Proposed pedagogical component	Support in science/STEM education	Qualification	Suggested key references
Relevance triggers learning	Strong support from context-based, science–technology–society (STS) and socio-scientific-issues education	Relevance should connect with learners’ lives, communities, aspirations, or societal problems.	Gilbert (2006); Stuckey et al. (2013)
Selecting and handling equipment	Supported as part of practical scientific and technological capability	Technology should not be reduced to equipment; it also includes systems, designs, processes, tools, and their social consequences.	Mitcham (1994); de Vries (2005)
Using equipment to develop process skills	Supported through inquiry, experimentation, and practical work	Contemporary frameworks emphasize broad scientific practices, not only generic process skills.	National Research Council [NRC] (2012); Millar (2010)
Constructing scientific knowledge through activity	Strongly supported by inquiry-oriented and constructivist approaches	Practical activity supports conceptual learning when accompanied by reasoning, modeling, explanation, and reflection.	Driver et al. (1994); Abrahams and Millar (2008)
Developing skills, attitudes, and values	Supported by scientific-literacy, STS, and socio-scientific-issues traditions	Values education should enable reasoned evaluation rather than impose predetermined views.	Zeidler et al. (2005); Sadler (2011)
Discussing science in societal contexts	Strongly supported, particularly by “Vision II” scientific literacy and socio-scientific-issues education (Roberts, D. A. (2011)).	Discussion should address evidence, uncertainty, ethics, interests, and consequences.	Roberts (2011); Hodson (2011)
Promoting STEM careers	Relevant participation can strengthen interest, identity, and career awareness	Career aspirations are also shaped by identity, representation, socioeconomic conditions, and access.	Archer et al. (2012)
Supporting societal development	Consistent with education for scientific literacy and responsible citizenship	This is a broad, distal goal that cannot be attributed to classroom instruction alone.	Aikenhead (2006); Sjöström and Eilks (2018)

factors in issues such as climate change and sustainable energy. Concept mapping can make this reasoning visible when learners use meaningful linking phrases to express dynamic relationships and construct cycles or feedback loops. However, within the acaSTEMy project, quality also depends on concept-mapping proficiency; weak maps may reflect limited mapping skill rather than limited systems understanding (Safayeni et al., 2005; Tripto et al., 2013; Cañas et al., 2015).

The project also applies this approach by connecting pre-service and in-service teacher development through collaboration among universities, schools, ministries, industry partners, and other organizations across Europe. For classroom use, it is useful to distinguish simply identifying system components from more advanced systems thinking, e.g., tracing interactions across levels, recognizing feedback and change over time, and anticipating how a change in one part may affect the wider system (Verhoeff et al., 2018; Gilissen et al., 2020).

Digital Confidence

Digital confidence is not limited to technical proficiency. The acaSTEMy project recognizes that this includes selecting appropriate tools, using them pedagogically, evaluating their usefulness, troubleshooting problems, and helping learners develop digital literacy. Thus, the acaSTEMy project seeks to promote the confident, critical, creative, safe, and responsible use of digital technologies for learning, communication, collaboration, problem-solving, and participation in society (Council of the European Union, 2018; Redecker, 2017; Vuorikari et al., 2022).

Innovative Professional Development

Innovative professional development moves beyond isolated workshops toward flexible, research-informed, and practice-oriented learning pathways. Within the acaSTEMy project, these include micro-credentials, asynchronous online study, international cooperation, mobility, job shadowing, and classroom-focused implementation (AcaSTEMy Consortium, 2024; European Commission, n.d.; Council of the European Union, 2022; Darling-Hammond et al., 2017; Desimone, 2009).

OPERATIONALIZING THE PROJECT APPROACH THROUGH MODULES AND MICRO-CREDENTIALS; MODULES CONNECTING WITH SUSTAINABILITY AND INTRODUCING JOB SHADOWING

Modules and Micro-credentials Following the Three-stage Model

The acaSTEMy project translates its broad aims into modules and micro-credentials for teachers and teacher educators. The modules create structured opportunities to connect STEM curriculum learning with wider educational goals, while micro-credentials provide a flexible means of recognizing professional learning. Together, they enable competence aspirations to be enacted, adapted, and assessed.

Modules, for example, addressing transversal skills, health and medicine, the Green Deal, and sustainability guide teachers

in designing lessons in which students use STEM knowledge to investigate real issues, interpret evidence, communicate ideas, and evaluate responses. This approach is founded on the philosophy of education through science, in which science serves as a vehicle for achieving wider educational goals rather than being taught solely as a body of disciplinary content. The approach aims to strengthen students' scientific and technological literacy by integrating conceptual understanding with inquiry skills, personal development, social values, communication, and informed decision-making. It utilizes a student-centered, constructivist three-stage model (Holbrook and Rannikmäe, 2014) as indicated below:

- Stage 1. Socio-scientific relevance. Learning begins with a familiar, relevant scenario that stimulates intrinsic motivation
- Stage 2. Inquiry and conceptual learning. Students investigate the issue and develop the scientific concepts needed to understand it
- Stage 3. Societal decision-making and reflection. Students consolidate and apply their learning through reasoning, discussion, and evidence-informed decision-making.

This sequence connects relevance, inquiry, conceptual learning, and societal application in context-based STEM lessons addressing sustainability, health, and other societal issues (AcaSTEMy Consortium, 2024).

Connecting the Three-stage Model with Sustainability

The three-stage model provides a pedagogical bridge to the acaSTEMy project's focus on sustainability education. In the first stage, a familiar sustainability-related issue – such as climate change, resource use, public health, or biodiversity loss – establishes relevance and motivates learners. In the second stage, inquiry-based activities enable learners to develop and apply the scientific, technological, engineering, and mathematical knowledge and skills needed to investigate causes, consequences, and responses. In the third stage, learners return to the original context, consolidate their knowledge, consider environmental, social, and economic dimensions, evaluate alternative solutions, and make evidence-informed decisions.

The model therefore extends sustainability learning beyond factual knowledge toward systems thinking, critical thinking, values, collaboration, and agency. This progression is consistent with education through science (Holbrook and Rannikmäe, 2007; 2009), the sustainability competences identified in GreenComp (Bianchi et al., 2022), and the acaSTEMy project aim of strengthening teachers' transversal competences and their capacity to educate learners for green transition.

Within this approach, science supports conceptual understanding; technology supplies tools, equipment, and digital resources for investigation, whereby experimentation and inquiry enable students to generate evidence and draw conclusions, and mathematics supports measurement, analysis, modeling, and interpretation. These elements feed

into reflective decision-making, through which students consider how scientific knowledge relates to societal needs, responsibilities, and possible futures.

Including Job Shadowing

Job shadowing is another route through which the acaSTEMy project seeks to operationalize its aims. It allows teachers and teacher educators to observe professional practice in authentic settings and reflect on how STEM knowledge, transversal competences, and professional judgment are used in context. In this way, job shadowing can bridge formal, module-based learning and the lived practices of STEM education, research, industry, and community engagement. The Erasmus+ Program Guide defines job shadowing as an experiential learning centered on participative observation, the acquisition of transversal skills, the exchange of good practice, and the development of long-term partnerships (European Commission, 2025).

The transformative competences of creating new value, reconciling tensions and dilemmas, and taking responsibility provide a focal lens for job shadowing. They help direct transversal competences toward responsible action in complex situations, particularly those involving sustainability, health, digital transformation, and inclusive STEM education.

A project-specific study in Science Education International (Cavas and Mercan, 2025) examines the effects of shadowing within the acaSTEMy project framework on science teachers' and postgraduate students' career perceptions and professional awareness. It considers how pre-service and in-service teachers can observe interdisciplinary STEM contexts and examine how scientific knowledge functions in research centers, innovation ecosystems, and industry.

More broadly, research on job shadowing as workplace learning in teacher education (Makovec, 2021) can examine how structured passive and active observation can help learners translate faculty-based theoretical insights into real-world work environments.

Expected Outputs from the AcaSTEMy Project

Transversal and transformative competences in career orientation

The acaSTEMy project promotes transversal competences through modules, micro-credentials, job shadowing, and teaching approaches aligned with the three-stage model. Critical thinking, communication, collaboration, digital competence, self-management, and learning to learn support career exploration and adaptability. Transformative competences add a reflective dimension by asking learners to consider the contribution they wish to make, the problems they want to help solve, and the values and responsibilities associated with future work (Hanesová and Theodoulides, 2022; OECD, 2019).

The OECD (2019) competences of creating new value, reconciling tensions and dilemmas, and taking responsibility are particularly relevant to career orientation. In job-shadowing

contexts, learners can observe how professionals communicate; solve problems; use technology; manage uncertainty; negotiate trade-offs; and consider social, environmental, and ethical consequences. Career education can therefore move beyond occupational awareness toward reflection on how STEM-related work contributes responsibly to society.

Strategic thinking

Strategic thinking is the action-oriented bridge between transformative competences and classroom practice. It involves understanding complex systems, considering alternative and desirable futures, comparing possible courses of action, anticipating intended and unintended consequences, recognizing trade-offs, and selecting responsible and feasible strategies for change (Wiek et al., 2011; OECD, 2019; Bianchi et al., 2022; Laherto et al., 2023). In this sense, strategic thinking integrates systems thinking, futures thinking, values-based judgment, evidence-informed decision-making, and action competence.

This interpretation is consistent with the OECD Learning Compass 2030, which emphasizes learners' capacity to create new value, reconcile tensions and dilemmas, and take responsibility (OECD, 2019) and with the European GreenComp framework, which connects sustainability learning with embracing complexity, envisioning sustainable futures, and acting for sustainability (Bianchi et al., 2022). More recent

guidance similarly stresses that sustainability and climate education should be holistic, scientifically grounded, justice-oriented, and action-oriented (UNESCO, 2024).

Strategic thinking therefore moves learners beyond asking how to fix a problem toward examining the system, affected stakeholders, relevant evidence and uncertainty, desired futures, alternative actions, values and trade-offs, feasibility, responsibility, and criteria for evaluating whether a chosen strategy works.

This matters particularly in science education because authentic issues involving health, medicine, sustainability, biodiversity, food production, climate change, energy, and emerging technologies are rarely purely technical. They involve scientific evidence together with uncertainty, values, risks, stakeholder perspectives, competing priorities, and short- and long-term consequences. Future-oriented science education therefore needs to enable learners not only to understand scientific knowledge but also to use that knowledge when imagining possible futures and making responsible decisions about action (Laherto et al., 2023; UNESCO, 2024).

The following Table 2 seeks to illustrate how the acaSTEMy project recognizes how the three transformative competences and transversal competences in general contribute to strategic thinking, giving illustrative outcomes by way of examples.

Table 2: Contribution of transformative and transversal competences to strategic thinking

Competence	Contribution of Strategic Thinking	Illustrative outcome	Relevant references
Creating new value	Supports the generation, comparison, and development of new solutions, practices, strategies, or possible futures. Learners use evidence and creativity to move beyond existing practices and consider how conditions might be improved.	Developing a more sustainable olive-growing strategy or designing a safer medicine-use campaign.	OECD (2019); Bianchi et al. (2022); Laherto et al. (2023)
Reconciling tensions and dilemmas	Makes competing priorities, stakeholder interests, values, uncertainties, and short- and long-term consequences visible and supports reasoned comparison of alternatives and trade-offs.	Balancing food production with biodiversity conservation, or balancing effective pain relief with the risk of medicine misuse or overdose.	OECD (2019); Bianchi et al. (2022); UNESCO (2024)
Taking responsibility	Requires learners to anticipate the consequences of possible actions, consider ethical and societal implications, justify decisions, and reflect on responsibility for implementation and outcomes.	Explaining what should be done, why it should be done, who should be involved, and how the consequences of the action should be evaluated.	OECD (2019); Bianchi et al. (2022); UNESCO (2024)
Systems thinking	Enables learners to identify relationships among scientific, environmental, technological, social, economic, and political dimensions of an issue and to recognize feedback, interdependence, and unintended consequences.	Mapping how agricultural practices influence soil, water, biodiversity, food production, farmers, consumers, and local economies before proposing an intervention.	Wiek et al. (2011); Bianchi et al. (2022); Laherto et al. (2023)
Futures thinking	Encourages learners to explore possible, probable, and desirable futures and to consider how present choices may influence longer-term outcomes.	Comparing alternative future scenarios for energy production, food systems, biodiversity protection, or public health.	Bianchi et al. (2022); Laherto et al. (2023); UNESCO (2024)
Transversal competences	Mobilizes critical thinking, problem-solving, creativity, collaboration, communication, digital competence, evidence evaluation, and decision-making in response to complex authentic problems.	Evidence-informed teamwork in which learners analyze information, evaluate alternatives, negotiate different perspectives, communicate a justified decision, and propose action.	OECD (2019); Bianchi et al. (2022); UNESCO (2024)
Action for sustainability	Translates analysis and judgment into realistic individual or collective action and requires learners to consider feasibility, stakeholders, implementation, monitoring, and revision of the chosen strategy.	Designing, implementing, and evaluating a school or community initiative addressing waste, biodiversity, energy use, sustainable food, or public health.	Bianchi et al. (2022); Laherto et al. (2023); UNESCO (2024)

The acaSTEMy project recognizes that transformative competences provide a future-oriented and responsibility-focused direction, transversal competences provide the capabilities, while strategic thinking connects the two through a process of analysis, judgment, and action.

A Common Structure for the AcaSTEMy Project Teacher In-service Modules (Sample Modules are Indicated in Appendices 1 and 2)

The acaSTEMy project modules – including those addressing Health and Medicine and the Green Deal – share a unified strategic structure comprising five core dimensions:

- **Mapping the System:** Identifying the scientific, social, ethical, economic, and environmental dimensions of an issue. Concept mapping serves as a primary tool to make these components and relationships explicit. Where appropriate, teachers can guide learners to evolve an initial descriptive concept map into a more dynamic model that illustrates how changes propagate through the system and where feedback loops occur.
- **Exploring Possible Futures:** Evaluating potential educational pathways by considering desirable, undesirable, likely, and disruptive teaching scenarios.
- **Identifying Tensions:** Examining systemic conflicts, such as individual freedom versus public health, innovation versus safety, or economic growth versus ecological limits.
- **Designing Potential Action:** Developing classroom activities where students propose evidence-informed action at the individual, school, community, or policy level.
- **Reflecting and Assessing “Responsibility:”** Broadening assessment beyond traditional knowledge (the understanding of facts, formulas, and theories). The acaSTEMy project framework holistically evaluates reasoning through transversal competences; ethical awareness of the social and environmental impacts of STEM solutions; agency (taking initiative; ownership of learning; applying skills independently); and collaboration (working effectively in groups, communicating ideas, and co-creating solutions).

Furthermore, this structure embeds the three-stage teaching model established by Holbrook and Rannikmäe (2014) to systematically enhance both Transversal and Transformative Competences, as illustrated in Table 3.

The table shows that the “three-stage teaching” approach provides a teaching and learning route from relevance, through scientific learning, to responsible societal action. Transversal competences can be developed throughout the teaching sequence, while transformative competences become most visible when students use scientific understanding to address “dilemmas” and make “reasoned decisions.” By relating to transformative competences, the acaSTEMy project seeks to give the three-stage model a future-oriented and responsibility-focused purpose, i.e., students learn science so that they can use it to make informed, ethical, and strategic decisions about issues affecting present and future society.

A future-oriented reflection is particularly important in the third teaching stage, whereby students can reflect on transformative-related questions, such as:

- What kind of future do we want?
- What choices could lead toward that future?
- Who is affected by these choices?
- What tensions or dilemmas must be addressed?
- What responsibilities do individuals, communities, professionals, and policymakers have?

The incorporation of transformative competences gives the three-stage model approach a future-oriented and responsibility-focused purpose, whereby students learn science so that they can use it to make informed, ethical, and strategic decisions about issues affecting present and future society.

Paying Attention to Evidence and Implications within the AcaSTEMy project

- **The Challenge of Automaticity:** Students do not automatically learn to make informed, ethical, and strategic decisions merely by studying science content. Developing the OECD’s three core Transformative Competencies – creating new value, reconciling tensions, and taking responsibility – requires explicit pedagogical intent.
- **Global Policy Alignment:** Major international policy instruments explicitly position socio-scientific decision-making as a primary goal of 21st-century scientific literacy:
 - **OECD PISA 2025 Science Framework:** Focuses science education on a learner’s capacity to engage with science-related issues, execute systems thinking, and to take action to promote sustainability.

Table 3: Relationships among the three-stage model, transversal competences, and transformative competences

Model stages	Main learning process	Transversal competences	Transformative competences
1. Socio-scientific relevance	Learners encounter a meaningful real-world issue, ask questions, and identify information needs.	Communication, Perspective-taking, Collaboration, and Connection with everyday life.	Introduces Tensions, Uncertainty, and Responsibility.
2. Scientific inquiry and conceptual learning	Learners investigate, experiment, analyze data, use technology, and develop explanations.	Critical thinking, Problem-solving, Collaboration, Digital competence, Data literacy, Self-management, and Creativity.	Provides the conceptual foundation for responsible decisions.
3. Societal decision-making and reflection	Learners debate, role-play, recommend action, and justify decisions.	Argumentation, teamwork, Communication, Ethical reasoning, and Evidence-based justification.	Makes explicit “Creating new value,” “Reconciling dilemmas,” and “Taking responsibility.”

- US National Research Council (2012): Argues that graduates must possess sufficient scientific literacy to actively participate in public discussions and act as careful consumers of technical information.
- European Commission (2015): Emphasizes that science education must prepare citizens to participate responsibly in science-informed decision-making and innovation.
- UNESCO (2020): Asserts that education must equip learners to take responsible action for environmental integrity, social justice, and future generations.
- Evidence-Based Solutions: Empirical research confirms that this decision-making capacity can be structurally cultivated. Specifically, well-designed Socio-Scientific Issues (SSI) frameworks, structured Inquiry and Argumentation models, and tools like concept mapping provide the necessary cognitive scaffolding to assess systems thinking (e.g., Tripto et al., 2013).
- Structural Implementation: Utilizing systematic instructional models – such as the Three-Stage Approach (moving seamlessly from a motivating societal scenario, through scientific inquiry, to ethical socio-scientific decision-making) – provides a proven curriculum pathway to translate these global policy goals into measurable student agency.

DISCUSSION AND CONCLUSION

For the acaSTEMy project, the most defensible conclusion is that the project evidence, considered together with wider research and European policy frameworks, supports the development of science and STEM education in which conceptual understanding relates to learners' ability to apply knowledge in informed, ethical, and strategically reasoned ways to authentic societal issues. This orientation is particularly visible in the acaSTEMy project's focus on socio-scientific issues, sustainability, health and medicine, transversal competences, systems thinking, and concept mapping.

These conclusions should not be overstated. AcaSTEMy is a Teacher Academy project focused on developing, piloting, and sharing approaches to teacher education and professional learning rather than a large-scale causal intervention study. Its contribution is therefore strongest in translating research-informed principles into modules, digital resources, micro-credentials, mobility formats, and classroom-oriented practice across European contexts.

Operationalizing the Future of STEM Education

The acaSTEMy project provides a transferable framework for developing more relevant, connected, and competence-oriented STEM education across diverse European contexts. Rather than treating scientific content as an end in itself, the project encourages teachers to connect conceptual learning with authentic societal and practical contexts, including health, medicine, sustainability, energy, food production, digitalization, and diversity.

Within this approach, scientific inquiry remains central, but it relates to evidence evaluation, argumentation, systems thinking, collaboration, and societal decision-making. The three-stage model illustrates this progression particularly clearly: Learners first encounter a meaningful context, then develop the scientific understanding needed to address it, and finally use evidence and reasoning to consider possible decisions and actions.

Operationalizing such priorities through initial teacher education and CPD is an important condition for sustainable change. The acaSTEMy project has therefore focused not only on classroom materials but also on developing teachers' digital competence, transversal competences, sustainability-related knowledge, interdisciplinary collaboration, and capacity to design context-based STEM learning. The modules, micro-credential designs, and mobility experiences provide different professional-learning routes through which these competences can be developed and shared.

The project experience suggests that teacher professional learning is particularly valuable when scientific content, pedagogy, societal relevance, and opportunities for reflection are addressed together, rather than as separate elements.

Challenges and Limitations

Implementation nevertheless involves several important challenges.

- Teacher preparation and disciplinary traditions. Moving toward more interdisciplinary, context-based, and competence-oriented STEM teaching requires substantial pedagogical adjustment. Teachers may be confident within their own scientific discipline while having less experience with interdisciplinary planning, socio-scientific discussion, systems thinking, engineering-related activities, or digital pedagogies. Sustained professional development and opportunities for collaboration are therefore important.
- Resource and infrastructure differences. Schools and teacher-education institutions differ in access to digital technologies, laboratory resources, specialist support, collaborative spaces, and opportunities to work with external organizations. The acaSTEMy project approaches, therefore, need to remain adaptable to different institutional and national contexts rather than depending on one resource-intensive model.
- Sustainability of mobility and partnerships. Job shadowing, international visits, co-supervision and partnerships with schools, science centers, professional organizations, and industry can enrich professional learning, but they require coordination, institutional commitment, time, and funding. The acaSTEMy project experience demonstrates the feasibility of such formats in different contexts but does not imply that identical arrangements can simply be transferred to every institution.
- Limits of the evidence base. The acaSTEMy project provides evidence from development, piloting, participant

experiences, and project-related studies, but not all activities are designed as controlled research interventions. Claims concerning long-term effects on teacher practice, student learning, STEM identity, or system-level transformation therefore require further investigation.

Recommendations for European Policymakers

The acaSTEMy project experience suggests four priorities for European and national policy: recognize high-quality micro-credentials and flexible CPD; ensure curricula and assessment make space for inquiry, interdisciplinary problem-solving, sustainability, digital competence, and responsible decision-making; sustain opportunities for teacher mobility and cross-border professional learning; and strengthen partnerships among universities, schools, science centers, public institutions, professional organizations, and industry. Policy should favor sustained professional learning in which teachers design, implement, reflect on, and refine practice rather than relying primarily on isolated training events.

Recommendations for STEM Educators

STEM educators can translate these principles into practice by beginning with meaningful health, environmental, technological, or societal contexts; making system relationships visible through concept maps and related representations; connecting disciplines when educationally meaningful while retaining necessary disciplinary depth; extending practical work through inquiry, evidence interpretation, argumentation, and reflection; and giving learners opportunities to compare alternatives, consider stakeholders and consequences, and justify proposed actions. Professional-learning networks, acaSTEMy project modules, digital resources, and mobility experiences can support continued adaptation of these approaches.

Overall, the acaSTEMy project positions STEM education in relation not only to disciplinary knowledge and future employment, but also to scientific literacy, responsible citizenship, and learners' capacity to respond to complex societal challenges. Its contribution is a coherent set of research-informed principles and professional-learning structures, while further research and longer-term evaluation remain necessary.

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REFERENCES

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning

- method in school science. *International Journal of Science Education*, 30(14), 1945-1969.
- AcaSTEMy Consortium. (2024). *Deliverable 4.1: Operational Structures and Digital-Skills Materials*. Erasmus+ Teacher Academies Project (acaSTEMy.eu).
- Aikenhead, G.S. (2006). *Science Education for Everyday Life: Evidence-Based Practice*. New York: Teachers College Press.
- Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012). “Balancing acts”: Elementary school girls' negotiations of feminine identities and science aspirations. *Science Education*, 96(6), 967-989.
- Bianchi, G., Pisiotis, U., & Cabrera Giraldez, M. (2022). *GreenComp: The European Sustainability Competence Framework*. Luxembourg: Publications Office of the European Union.
- Cañas, A.J., Novak, J.D., & Reiska, P. (2015). How good is my concept map? Am I a good Cmapper? *Knowledge Management and E-Learning*, 7(1), 6-19.
- Cavas, B., & Mercan, B. (2025). The effect of job shadowing practices on science teachers' career perceptions. *Science Education International*, 36(4), 503-509.
- Chen, S., & Wei, B. (2022). Development and validation of an instrument to measure high school students' science identity in science learning. *Research in Science Education*, 52, 111-126.
- Council of the European Union. (2022). Council recommendation of 16 June 2022 on learning for the green transition and sustainable development. *Official Journal of the European Union*, 65(C243), 1-9.
- Council of the European Union. (2018). Council Recommendation of 22 May 2018 on key competences for lifelong learning. *Official Journal of the European Union*, 61(C189), 1-13.
- Darling-Hammond, L., Hyler, M.E., & Gardner, M. (2017). *Effective Teacher Professional Development*. Washington, DC: Learning Policy Institute.
- Desimone, L.M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, 38(3), 181-199.
- De Vries, M.J. (2005). *Teaching about Technology: An Introduction to the Philosophy of Technology for Non-Philosophers*. Berlin: Springer.
- Dou, R., & Cian, H. (2022). Constructing STEM identity: An expanded structural model for STEM identity research. *Journal of Research in Science Teaching*, 59(3), 458-490.
- Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.
- European Commission. (2025). *Erasmus+ Programme Guide: Glossary of Common Terms*. Luxembourg: European Education and Culture Executive Agency.
- European Commission. (2015). *Science Education for Responsible Citizenship: Report to the European Commission of the Expert Group on Science Education*. Luxembourg: Publications Office of the European Union.
- European Commission. (n.d.). *Erasmus+ Teacher Academies*. European Education Area. Available from: <https://education.ec.europa.eu/education-levels/school-education/erasmus-teacher-academies> [Last accessed on 2026 Sep 10]
- Evagorou, M., Nielsen, J.A., & Dillon, J. (Eds.). (2020). *Science Teacher Education for Responsible Citizenship: Towards a Pedagogy for Relevance through Socioscientific Issues*. Berlin: Springer.
- Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, 7, 24.
- Gilbert, J.K. (2006). On the nature of “context” in chemical education. *International Journal of Science Education*, 28(9), 957-976.
- Gilissen, M.G.R., Knippels, M.C.P.J., & Van Joolingen, W.R. (2020). Bringing systems thinking into the classroom. *International Journal of Science Education*, 42(8), 1253-1280.
- Hanesová, D., & Theodoulides, L. (2022). *Mastering Transversal Competences in a Higher Education Environment through Processes of Critical Thinking and Reflection*. Slovakia: Matej Bel University.
- Hodson, D. (2011). *Looking to the Future: Building a Curriculum for Social Activism*. Netherlands: Sense Publishers.
- Holbrook, J., & Rannikmäe, M. (2014). The philosophy and approach on which the PROFILES project is based. *Center for Educational Policy*

- Studies Journal*, 4(1), 9-29.
- Holbrook, J., & Rannikmäe, M. (2009). The meaning of scientific literacy. *International Journal of Environmental and Science Education*, 4(3), 275-288.
- Holbrook, J., & Rannikmäe, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education*, 29(11), 1347-1362.
- Kelley, T.R., & Knowles, J.G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), 1-11.
- Laherto, A., Rasa, T., Miani, L., Levrini, O., & Erduran, S. (2023). Future-oriented science education building sustainability competences: An approach to the European GreenComp framework. In: Fazio, X., (Ed.), *Science Curriculum for the Anthropocene, Volume 2: Curriculum Models for Our Collective Future*. London: Palgrave Macmillan, pp. 83-105.
- Le, H.C., Nguyen, V.H., & Nguyen, T.L. (2023). Integrated STEM approaches and associated outcomes of K-12 student learning: A systematic review. *Education Sciences*, 13(3), 297.
- Makovec, D. (2021). Learning potentials of job shadowing in teacher education. *International Journal of Learning Teaching and Educational Research*, 20(12), 255-266.
- McLure, F.I., Tang, K.S., & Williams, P.J. (2022). What do integrated STEM projects look like in middle school and high school classrooms? A systematic literature review of empirical studies of iSTEM projects. *International Journal of STEM Education*, 9, 73.
- Millar, R. (2010). *Analysing Practical Science Activities to Assess and Improve their Effectiveness*. London: Association for Science Education.
- Mitcham, C. (1994). *Thinking through Technology: The Path between Engineering and Philosophy*. United States: University of Chicago Press.
- Moore, T.J., Stohlmann, M.S., Wang, H.H., Tank, K.M., Glancy, A.W., & Roehrig, G.H. (2014). Implementation and integration of engineering in K-12 STEM education. In: Purzer, S., Strobel, J., & Cardella, M., (Eds.), *Engineering in Pre-College Settings*. United States: Purdue University Press, p35-60.
- National Academy of Engineering, & National Research Council. (2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. United States: The National Academies Press.
- National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. United States: National Academies Press.
- Organisation for Economic Co-operation and Development. (2019). *Transformative Competencies for 2030: OECD Learning Compass 2030 Concept Note*. United States: OECD Publishing.
- Organisation for Economic Co-operation and Development. (OECD). (2019). *PISA 2021 Science Framework*. United States: OECD Publishing.
- Redecker, C. (2017). In: Punie, Y., (Ed.). *European Framework for the Digital Competence of Educators: DigCompEdu*. Luxembourg: Publications Office of the European Union.
- Reynante, B.M., Selbach-Allen, M.E., & Pimentel, D.R. (2020). Exploring the promises and perils of integrated STEM through disciplinary practices and epistemologies. *Science and Education*, 29, 785-803.
- Roberts, D.A. (2011a). Competing visions of scientific literacy: The influence of a science curriculum policy image. In: Linder, C., Östman, L., Roberts, P., Wickman, P.O., Erickson, G., & MacKinnon, A., (Eds.), *Exploring the Landscape of Scientific Literacy*. London: Routledge, pp. 11-27.
- Roberts, D.A. (2011b). Competing visions of scientific literacy. In: Abell, S.K., & Lederman, N.G., (Eds.), *Handbook of Research on Science Education*. London: Routledge, pp. 729-780.
- Roehrig, G.H., Dare, E.A., Ellis, J.A., & Ring-Whalen, E. (2021). Beyond the basics: A detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, 3, 11.
- Sadler, T.D. (Ed.). (2011). *Socio-Scientific Issues in the Classroom: Teaching, Learning and Research*. Berlin: Springer.
- Safayeni, F., Derbentseva, N., & Cañas, A.J. (2005). A theoretical note on concepts and the need for cyclic concept maps. *Journal of Research in Science Teaching*, 42(7), 741-766.
- Sjöström, J., & Eilks, I. (2018). Reconsidering different visions of scientific literacy and science education based on the concept of Bildung. In: Dori, Y.J., Mevarech, Z.R., & Baker, D.R., (Eds.), *Cognition, Metacognition, and Culture in STEM Education*. Berlin: Springer, pp. 65-88.
- Starr, C.R., Hunter, L., Dunkin, R., Honig, S., Palomino, R., & Leaper, C. (2020). Engaging in science practices in classrooms predicts increases in undergraduates' STEM motivation, identity, and achievement: A short-term longitudinal study. *Journal of Research in Science Teaching*, 57(7), 1093-1118.
- Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education*, 49(1), 1-34.
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-De Pauw, J., Dehaene, W., Depaepe, P., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van De Velde, D., Van Dooren, W., Van De Wauwer, I., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1), 2.
- Tripto, J., Ben-Zvi Assaraf, O., & Amit, M. (2013). Mapping what they know: Concept maps as an effective tool for assessing students' systems thinking. *American Journal of Operations Research*, 3(1A), 73-84.
- UNESCO. (2024). *Greening Curriculum Guidance: Teaching and Learning for Climate Action*. France: UNESCO.
- UNESCO. (2020). *Education for Sustainable Development: A roadmap*. United Nations Educational, Scientific and Cultural Organization. Available from: <https://www.unesco.org> [Last accessed on 2026 Sep 09].
- UNESCO. (2017). *Education for Sustainable Development Goals: Learning Objectives*. Paris: UNESCO Publishing.
- Verhoeff, R.P., Knippels, M.C.P.J., Gilissen, M.G.R., & Boersma, K.T. (2018). The theoretical nature of systems thinking: Perspectives on systems thinking in biology education. *Frontiers in Education*, 3, 40.
- Vuorikari, R., Kluzer, S., & Punie, Y. (2022). *DigComp 2.2: The Digital Competence Framework for Citizens*. Luxembourg: Publications Office of the European Union.
- Wiek, A., Withycombe, L., & Redman, C.L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, 6(2), 203-218.
- Zeidler, D.L., Sadler, T.D., Simmons, M.L., & Howes, E.V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, 89(3), 357-377.

APPENDIX 1

Examples of Chemistry-oriented Modules on Health and Medicine within the AcaSTEMy Project

- Transformation/conversion of energy in the human body
- Functioning and disorders of the human immune system
- Use of various forms of radiation for disease diagnosis
- Health-conscious behavior in mitigating disorders
- Biochemical processes within the human body
- Importance of a healthy lifestyle
- Ageing as a normal collection of changes, biochemical processes in ageing
- Disorders (inherited and acquired) in biochemical processes in the human body
- Drug design and drug production and the role that quality control plays in it
- Application of biotechnology to the production of medicine and vaccines
- Application and the correct approach within gene therapy interventions, based on the effectiveness and monitoring of side effects
- Possible use and dangers/risks to the healthcare system from AI-based technologies.

APPENDIX 2

An Exemplar Biology-oriented Module on Green Deal

Possible focus areas associated with the Green Deal include climate-change mitigation and adaptation, renewable-energy transitions, the circular economy, biodiversity loss, sustainable food systems, transport, and urban planning, as well as a just transition that addresses energy poverty.

Examining a Localized Green Deal Case: Olive Growing

Olive growing offers a rich socio-scientific context because it connects irrigation, drought, soil erosion, biodiversity, carbon, pesticides, rural economies, exports, cultural heritage, and farmer livelihoods. The central question is not whether olive farming is simply “good” or “bad,” but: *How can olive production be redesigned so that it supports food production, rural livelihoods, soil and water conservation, biodiversity, and climate goals?*

A related strategic question is: *How can olive growing contribute to an enhanced Green Deal rather than merely comply with it?*

This module helps teachers move from teaching the Green Deal as policy content toward teaching *Green Deal thinking*. Olive growing becomes a concrete context in which the students’ reason scientifically, ethically, and strategically about sustainability.

The Green Deal Example: “Olive Oil Production: Good for Health but Bad for the Environment?”

Stage 1. The initial scenario (problem setting)

As an essential part of the Mediterranean diet, olive oil has a significant role in reducing inflammation, aiding digestion, and boosting overall health. The health benefits and taste have helped olive oil continue to be popular around the world, starting in the Mediterranean countries, but also in areas of the world that provide a welcome climate for olive groves, such as southern California. However, this figure has been growing annually as more people consider adding it to their diet for health reasons. Nowadays, it is consumed not only in all European countries but also all around the world. The European Union is the leading producer, consumer, and exporter of olive oil. The EU produces roughly 67% of the world’s olive oil. Around 4 million hectares, mainly in the EU Mediterranean countries, are dedicated to the cultivation of olive trees, combining traditional, intensive, and super-intensive groves.

Identifying the problem

A study carried out in 2014, by the National Institute for Agrarian and Veterinary Research, states that the olive tree is a typically Mediterranean crop that adapts well to drought. Indeed, olive groves have comparatively low water needs compared to other crops. Besides, maintaining vegetation cover and natural areas in olive groves enhances species diversity and consequently the ecosystem function in cultivated areas. However, due to the increasing demand for olive oil, related to its health benefits, we are assisting to an intensification of olive production, and consequently an increasing use of herbicides, with the consequent risks of nutrient loss, contamination of soil and water, and loss of biological diversity.

Stage 2. Explore and explain (inquiry-based and debate activity)

Problem-situation: Although olive tree production is traditionally a sustainable crop, the great demand for olive oil promotes the use of production techniques that are bad for the environment. How can we help to mitigate this problem?

Task: Imagine that you are part of a group of specialists that must propose some ideas for a model of development that could help to mitigate the problem identified (great demand versus sustainable practices).

Exploration and discussion on the different dimensions involved (environmental, economic, social, human health)

Activity: A Debate

As the demand for agricultural products increases, the debate over how to address that challenge can be polarized, pitting intensive agriculture (food production) and global commerce against local food systems and organic farms. Organize a debate between the different sectors of society (environmentalists, large producers, producers from small farms, consumers) – each group will assume one of the sectors previously selected – to discuss how to deal with this apparent dilemma:

... Increasing production to meet growing needs versus maintaining environmental balance...

Stage 3. Societal application (proposing a model seeking to answer the initial problem)

Analysis of practical solutions for sustainable production:

- a. Local sustainable measures – Analysis of a real case

Case study: Back to the Origins – Traditional olive oil production at Marvão (Portugal).

Discussion of a concrete example related to olive oil production, following traditional practices, which allowed not only the creation of a quality brand, promoting tourism and more sustainable consumption, but also the development of the local community.

- b. Large-scale sustainability measure

Experimental activity: Importance of using bioplastics in a more sustainable food industry – Gelatine-based bioplastic synthesis activity.

Discussion: What are the potential challenges and limitations of replacing conventional plastics with biopolymers like the one you synthesized?