Science with and for Society

Policy Brief

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Science education policies in the European Comission: towards responsible citizenship

General introduction

As the world becomes more inter-connected and competitive, and research and technological know-how expands, new opportunities as well as more complex challenges arise. Overcoming these challenges will require citizens to have a better understanding of science and technology if they are to actively participate in science-informed decision-making and help to solve the problems confronting us in the twenty first century. It will involve input from specialists and from stakeholder groups.

At the moment, Europe faces a shortfall in science-knowledgeable people at all levels of society and the economy. Over the last decade there has been an increase in the numbers of students leaving formal education with science qualifications. But, there has not been a parallel rise in the numbers interested in pursuing science related careers.

Science education research, innovation and practices must become more responsive to the needs and ambitions of European society and reflect its values. It should support citizens of all ages and talents in developing positive attitudes to science, and reflect the science that citizens need. Identified solutions must meet the highest ethical standards and help ensure sustainable societies into the future. This is a good time to expand opportunities for science learning, in formal, non-formal and informal settings. It is necessary to help all citizens acquire the necessary knowledge of and about science to participate actively and responsibly successfully throughout their lives.

Society, including learners at different educational levels, should be involved more in collaborative activities while collaboration is a key to success in today's world and the collaboration skills need to be assessed and evaluated. Social skills in broad are a target in itself in the learning process, including science learning. These skills are a prerequisite for other activities planned to improve science learning and ensure sustainability of open science.

The policy brief not only presents the rationale, challenges, objectives and guidelines for a new approach on science education, but offers the descriptions and main information of a broad range of best practice case studies not only from European projects but also international models or concepts.

1. Why Science Education?

Building capacities and developing innovative ways of connecting science to society is a priority under Horizon 2020.

Knowledge of and about science are integral to preparing our population to be actively engaged and responsible citizens, creative and innovative, able to work collaboratively, and fully aware of and conversant with the complex challenges facing society. It helps us to explain and understand our world, to guide technological development and innovation, and to forecast and plan for the future.

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Science education is vital:

- To promote a culture of scientific thinking and inspire young people in using evidence-based reasoning for decision making, as opposed to values and reasoning processes that are less reliable or that are only based on beliefs or feelings;
- To ensure citizens have the confidence, knowledge and skills to participate actively in an increasingly complex scientific and technological world;
- To develop the competencies for problem-solving and innovation, as well as analytical and critical thinking that are necessary to empower citizens to lead personally fulfilling, socially responsible and professionally-engaged lives promoting solidarity at national, European and global level;
- To inspire children and students of all ages and talents to aspire the careers in science and other occupations and professions that underpin our knowledge and innovation-intensive societies and economies and in which they can be creative and accomplished;
- To enable public, private and third-sector organisations, based in Europe, to find appropriately skilled and knowledgeable people, and to promote and nurture an innovative Europe-wide environment where companies and other stakeholders from around the world want to invest, work and live;
- To empower active and responsible participation in public science communication, debates and decision-making as active engagement of European citizens in the big challenges facing humanity today.

Science learning helps us to interpret and understand our world, to manage risk and put uncertainty into perspective, to guide technological development and innovation, and to forecast and plan for the future. It improves job prospects, cultural awareness, and our ability to act as well-informed citizens.

For some people, science refers only to knowledge of physical systems, living systems, earth and space systems and technology. Sometimes it refers specifically to STEM (science, technology, engineering and mathematical) disciplines. Too often, science is seen as something separate from all other subjects or disciplines in education, disconnected from people's lives beyond school.

But, science influences all parts of our lives and our decision-making processes. Along with language and artistic literacy, knowledge of science and mathematics is the basis for personal accomplishment and responsible citizenship, social and economic development, and a benchmark of innovation, entrepreneurship and competitiveness in our global world.

A more integrative approach is required. We need to link science or STEM with all other subjects or disciplines at all levels of education. This means taking other disciplines as a starting point to introduce scientific thinking and inquiry approach, and also learning through science. This also means strengthening links and interaction between formal, non-formal and informal science education. Accordingly, the focus should shift from STEM to STEAM (within which the A usually shows link to Arts but it can also be defined in a way that it includes ALL other disciplines and informal science education).

This can help to make science more attractive to young people, increase society's appetite for innovation, and open up further research and innovation activities. Making science education and careers attractive for young people is an ambitious goal, since it targets to drastically improve science and technology-literacy in our society.

Europe needs more scientists. Failure to encourage sufficient numbers of students and adults to sustain their interest in science – into and through technical, vocational, undergraduate and graduate/ doctoral studies – could undermine the success of *Europe 2020 strategy.*

- A high level of scientific literacy among European citizens is both a democratic and economic necessity, since a rigorous understanding and use of scientific knowledge in decision-making are required.
- The skills gap between future jobs and actual STEM candidates or graduates is alarming in many European countries.
- Future welfare through smart innovation calls for STEM skills that should be applied in different disciplines beyond science.
- Science and Technology is an important part of our European cultural heritage and should as such be passed on to the next generation.

STEM shortages are prevalent throughout Europe

Germany 2012	Netherlands 2011-2016	France 2011	Switzerland 2009
Shortage 200 000 STEM graduates (mainly engineers)	**Shortage** 25 000 per year technical skills graduates	**Shortage** Delta – 10 000 30 000 supply for 40 000 offer	**Shortage** 2000 candidates for 16 000 jobs
Cost 20 billions per year	**Need to replace staff** 20% of engineers > 55 years are still active in DE, CH and DK		**Cost** 2 billions per year

inGenious

Source: InGenious, various sources

Innovative formal and informal science education teaching and learning is important in order to raise both young boys' and girls' awareness of the different aspects encompassing science and technology in today's society and to address the challenges faced by young people when pursuing careers in Science, Technology, Engineering and Mathematics (STEM).

2. Key objectives for Science Education

The science education experts recommend six key objectives, which in combination can help to stimulate the systemic changes required to generate a sustainable effect across our societies and in our communities.

1. Science education should be an essential component of a learning continuum for all, from pre-school, high school and tertiary education to active engaged citizenship.

This would enable all citizens to explore, understand and apply science and technology in their daily life and engage in the democratic debate.

Education system should address socio-economic, gender and cultural inequalities in order to widen access and provide all talents with the opportunities to pursue excellence in both the processes of learning and the learning outcomes.

As part of the shift from preparing people for lifelong employment to lifelong employability, people need to leave compulsory education with knowledge of and about science and acquiring skills that are applicable in different domains, deep familiarity with the culture and values of science, positive attitudes towards and a willingness to learn more about science

Curiosity about the world around us, learning to act and think like a scientist, and understand the Nature of Science provide a solid foundation for future success.

2. Science education should focus on competences with an emphasis on learning through science and shifting from STEM to STEAM (Science & Technology interpreted through Engineering & Arts) by linking science with other subjects and disciplines.

Success in the knowledge society depends upon acquiring competences rather than simply learning facts. As competence we understand any proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development. In the context of the European Qualifications Framework, competence is described in terms of responsibility and autonomy. Examples of scientific competences include argumentation, problem solving, modelling, innovation, creativity, design and investigation. Examples of transversal competences include communication, collaboration, self-regulation, openness and persistence. All competences require content, procedural and epistemic knowledge.

Science group work has an important role in developing these competences. Being able to collaborate, listen to the ideas of others, think critically, be creative and take initiative, solve problems and assess risk, take decisions and constructively manage emotions are interdependent. They are considered essential for success in adult life, and the basis for further lifelong learning. They also contribute to active citizenship at local, national, European and global level.

Science learning is not just a matter of understanding concepts, this have been proven for many students. Robust science learning emerges in the form of enculturation into the

values and practices of scientific communities. It involves the development of a small set of coherent conceptual models and competences. The capability to construct conceptual models and to apply them in order to generate predictions and interpretations in previously unfamiliar situations is an important indicator for robust science learning. Robust science learning also includes an awareness of the nature of science as a human enterprise for developing reliable knowledge as well as a set of epistemological convictions and the motivation to identify and investigate phenomena, to seek consistency in the application of ideas and to work with others in searching for better and better explanations.

3. The quality of teaching, teacher induction, pre-service preparation and in-service professional development, should be enhanced to improve the depth and quality of learning outcomes.

Since the quality of education and the learning outcomes are the bedrock of the future society, we should aim to ensure the systemic changes to teacher induction and pre- and in-service professional development as well as what happens in classrooms; we need to shift the focus on how students and teachers teach and learn together. Many of these actions are within the direct control of individual teachers, course leaders and schools.

The quality of an education system cannot exceed the quality of its teachers but schools and science teachers do not work in isolation. Where change is carried out with the support of others, through collaborative networks of educators, students, science education researchers and other stakeholders, it is likely to be more invigorating and successful for everyone. Research shows that engaging with colleagues in professional development programmes increases interest in improving teaching and in realigning its priorities to include the teaching of competences. Facilitating greater opportunities to exchange ideas with enterprise and civil society stakeholders brings real-life problems into science education preparation and continuous professional development.

4. Collaboration between formal, non-formal and informal educational providers, industry and civil society organisations 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 to improve employability and competitiveness.

Partnerships between teachers, students and stakeholders in science-related fields can offer exciting ways to introduce real-life challenges, with their ethical and social issues, into a classroom setting while also aiding problem-solving skills.

Research shows the value of collaborating across schools, families, researchers, informal science educators, enterprise and civil society organisations. Collaboration may also involve museums, science centres, parks and nature centres. Taking an approach to science education innovation that adopts the principles of RRI would make these voices more evident in setting the agenda for change and lead to benefits for all.

5. Greater attention should be given to promoting Responsible Research and Innovation (RRI) principles by enhancing public understanding of scientific findings and the capabilities to discuss their benefits and consequences.

Many organisations are already involved in science-based activities without thinking of themselves as developing science understanding, including, for example: recycling initiatives, patient support groups, community, health and environmental groups, gardening clubs, and children's computer coding groups. Novel approaches that place emphasis on learning and collective change such as those at the centre of health promotion, community arts and community and social development should be encouraged. This would help bring about a more inclusive science education, and help reduce socio-economic, gender, regional and other disparities.

Finding solutions to society's complex challenges involves a broader understanding of social and technological innovation. Valuing and evaluating the quality and outcomes of science education and science education research should take account of collaboration and stakeholder involvement, adherence to RRI values, internationalisation, and societal impact and benefit. This requires new ways to define and measure what counts as success that matches the objectives of science education for responsible citizenship.

The intended shift to more active participation by citizens in science reflects the growing realisation that participatory approaches, which respect human rights and meet the highest ethical standards, bring tangible benefits for all. Involving all citizens, from an early age and throughout the life-cycle, provides a valuable way to mainstream science education and create a more balanced science-informed society.

6. Emphasis should be placed on connecting innovation and science education strategies, at local, regional, national, European and international levels, taking into account societal needs and global developments.

Europe's challenges do not stop at city or national borders. What is promoted and undertaken at the European level is linked to complementary actions at the national and regional level. At the same time, attention should be focused on establishing and strengthening international collaboration and partnerships. Sharing knowledge of and about science education for responsible citizenship with colleagues across borders should be an intrinsic part of all initiatives, actively pursued with international partners, through joint projects, enhanced mobility for science educators, researchers, students, and key stakeholders. Adherence to the RRI principles is key to ensuring stakeholders to be involved throughout.

The emphasis on RRI creates a responsibility for science education to contribute to enhanced innovation in Europe but also to pervasive awareness of the benefits of ethical standards, accountability, transparency and citizen participation. Science education can only rise to this challenge by itself adopting the principles of responsibility and responsiveness. To meet the goals set out in this document there is a need for science education to become more responsive to societal challenges and priorities but also to adopt more open processes in setting priorities and in reflecting on outcomes. Links between local, regional, national science education and innovation strategies should be strengthened in order to remove regional, gender and socio-economic disparities across Europe. It is this prolonged, deep change that should be the focus of science education in Horizon 2020 and beyond.

Types of learning

Formal learning – learning that occurs in an organised and structured environment (e.g. in an education or training institution or on the job) and is explicitly designated as learning (in terms of objectives, time or resources). Formal learning is intentional from the learner's point of view. It typically leads to validation and certification.

Non-formal learning – learning which is embedded in planned activities not always explicitly designated as learning (in terms of learning objectives, learning time or learning support), but which contains an important learning element.

Non-formal learning is intentional from the learner's point of view. It can take place in museums, science camps/clubs, science fairs and festivals, visiting and working with industry, fab labs etc.

Informal learning – learning resulting from daily activities related to work, family or leisure. It is not organised or structured in terms of objectives, time or learning support. Informal learning is mostly unintentional from the learner's perspective.

STEM or STEAM

STEM – Teaching and learning in the fields of science, technology, engineering and mathematics. It typically includes educational activities across all grade levels – from pre-school to post-doctorate – in both formal (e.g., classrooms) and informal (e.g., afterschool programs) settings.

STEAM – An educational and innovation framework bringing science, technology, engineering and mathematics together with the arts/other disciplines (STEM + Art = STEAM or S-TEAM) and types of learners with the goal of being more engaging, creative and naturally successful for all members of any educational system.

Open schooling

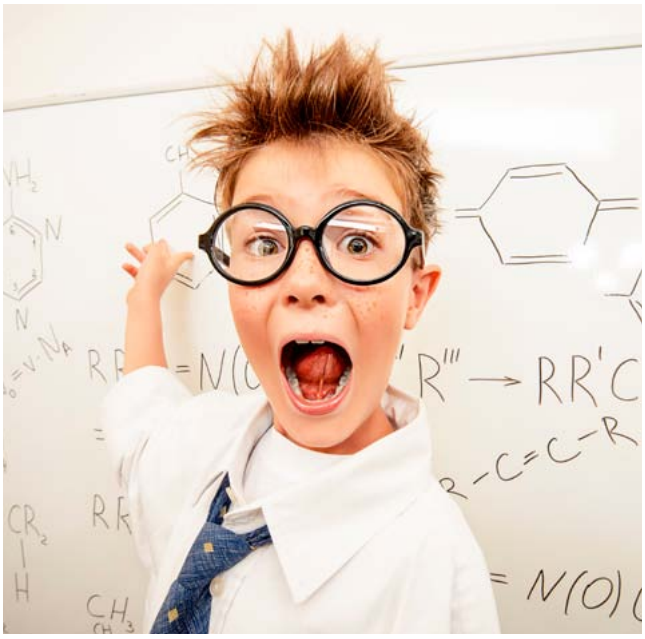
Institutions that promote partnerships with families and the local community with a view to engaging them in the teaching and learning processes but also to promote education as part of local community development. Encourage "open schooling" where (a) Schools, in cooperation with other stakeholders, become agents of community well-being, (b) Families are encouraged to become real partners in school life and activities, (c) Professionals from enterprise, civil and wider society are actively involved in bringing real-life projects into the classroom.

Open Educational Resources provide a strategic opportunity to improve the quality of education as well as facilitate policy dialogue, knowledge sharing and capacity building. Open Educational Resources are teaching, learning or research materials that are in the public domain or released with an intellectual property license that allows for free use, adaptation, and distribution.

3. Methodologies for a Responsible Science Education in Europe

Inquiry-based Science Education (IBSE)

Inquiry approaches to science education is any complex process of sense-making and constructing coherent conceptual models where students formulate questions, investigate relationships and phenomena, build new understandings, meanings and knowledge, communicate their learnings to others and apply their learning productively in unfamiliar situations. Inquiry-oriented science education engages students in: i) authentic, problem based learning activities where there may not be one correct answer; ii) experimental procedures, and reflective activities; iii) teaching – learning sequences where emergent student autonomy and self-regulation are emphasized; and iv) discursive argumentation and communication with peers ("talking science").



Problem Based Learning (PBL)

Problem-Based Learning is an instructional method of active learning centred on the investigation and resolution of real-world problems. When students identify the problems they investigate, they have a greater potential to stimulate young people's interest in science issues and the potential of solving problems with science. The problems should be identified by the problem solvers and the students as active (self-regulated) learners should be heavily involved in this.

Problem-Based Learning is driven by open-ended, unstructured and undefined problems with several solutions. The students can work in small collaborative groups as self-directed, active investigators while the teacher adopts the role as facilitator guiding the students in their investigations.

Practical work or Research Projects in Science Education

Practical work includes tasks in which students observe or manipulate real objects or materials in the laboratory, fieldwork or in the classroom, and it is often an integrated part of IBSE or PBL. It can develop a scientific attitude, such as open-mindedness and objectivity. However, scientific findings do not automatically emerge from the practical work itself. Therefore reflections over the findings and conversations among students or between teacher and students are essential to make links between observations and scientific findings.

4. Gender aspects in Science Education

Gender equality is a priority of the ERA roadmap and a key issue in RRI. Gender aspects in Science Education involve two main focus of interest: 1) gender inclusive participatory approaches (which challenge gender stereotypes and stimulate equal participation of girls, boys, women and men in science activities and in science careers); and 2) the Integration of Gender Analysis into Research (IGAR, which is aimed at avoiding gender biases in the production of science).

The gender inclusive approach is mainly aimed at encouraging girls and young women to enter academic and research careers in all scientific fields, especially in those related to engineering and technology. The European Parliament resolution of 9 September 2015 on women's careers in science and universities, and glass ceilings encountered (2014/2251(INI)) calls on the Commission and the Member States to promote:

- educational programmes which encourage synergies and positive links between STEM subjects and the arts and humanities and promote a gender perspective, facilitating the role women can play in making these links;
- positive female role models at all levels of education, including compulsory schooling and through to further and higher education and postgraduate level, and also in informal education and youth work (and for that recognises that promoting positive female role models includes taking measures to emphasise the historical and contemporary achievements of women in science and technology, entrepreneurship, and decision-making positions; and notes that such measures may include specific focus on International Women's Day, Science Weeks, and making use of existing best practice from Member States and across the world).

It also urges the Member States to develop effective and attractive STEM curricula and teaching methods to keep girls engaged in science, and to recognise and invest in teachers as drivers of cultural change, with their potential to boost the continuing participation of girls in science at school.

Hypatia, an EU-funded project, focus on this gender inclusive issue (particularly, it aims at changing the ways sciences are communicated to young people in and out of school to make them more gender inclusive).

A review of the scientific literature on girls and science education[1] identified four main topics: equity and access, curriculum and pedagogy, the nature and culture of science, and identity, all of them related to the gender inclusive focus with no specific consideration on the IGAR one.

The focus on IGAR is less developed and known so far as applied to science education. The GENDER-NET ERA-Net has launched an IGAR Tool aimed at assisting research funding and performing organizations as well as researchers and peer reviewers/evaluators with the know-how to integrate sex and gender considerations into policies, programmes, and projects, and to raise awareness about the importance of sex and gender in research and innovation. It also includes a section on Tools for IGAUC, which provides specific recommendations and models on Integrating Gender Analysis into University Curricula (IGAUC).

1 Brotman, Jennie S. & Moore, Felicia M. (2008). Girls and Science: A Review of Four Themes in the Science Education Literature. *Journal of Research in Science Teaching, 45(9),* 971-1002.

5. Resources

Benchmarks for Science Literacy (BSL)

- Eurobarometer 2005: Europeans, Science and Technology
- ASPIRES: Young People's science and career aspirations

Selection of Science Education projects in FP7 and HORIZON2020

- Ark of Inquiry project
- HEIRRI – Higher Education Institutions & Responsible Research Innovation
- Hypatia
- INGENIOUS – Shaping the future of maths and science education
- Go-Lab – Global Online Science Labs for Inquiry Learning at School
- RRI Tools – Foster Responsible Research and Innovation for society and with society
- PERFORM – Participatory Engagement with Scientific and Technological Research through Performance:
- PROFILES – Reflection Oriented Focus on Inquiry-based Learning and Education through Science
- Science Education Projects funded by FP6 (Science and Society), FP7 (Science in Society) and Horizon 2020 (Science with and for Society) programmes
- SiS.net2 – Network of National Contact Points for Science with and for Society in Horizon2020
- SCIENTIX – The communication for Science Education in Europe
- SCY – Science Created by You

Science Education policy documents and articles

- European Union (2012) Responsible research and Innovation: Europe's ability to respond to societal challenges, Brussels, European Union.
- RRI Tool Kit Science Education Material
- Science Education for Responsible Citizenship
- Open Innovation, Open Science, Open to the world – a vision for Europe
- Osborne J and Dillon J (2008) *Science education in Europe: Critical reflections: A report to the Nuffield Foundation*, London, Nuffield Foundation
- José Mariano Gago (Chairman), John Ziman, Paul Caro, Costas Constantinou, Graham Davies, Ilka Parchmannn, Miia Rannikmäe, Svein Sjøberg (2004) *Increasing Human Resources for Science and Technology In Europe:* Report at the EC conference EUROPE NEEDS MORE SCIENTISTS, Brussels, 2 April, 2004
- DeWitt, J., Archer, L. & Osborne, Nerdy, Brainy and Normal: Children's and Parents' Constructions of Those Who Are Highly Engaged with Science, J. Res Sci Educ (2012)

Network for national STEM education strategies

- EU STEM Coalition

Other interesting links

- European Schoolnet – Transforming education in Europe