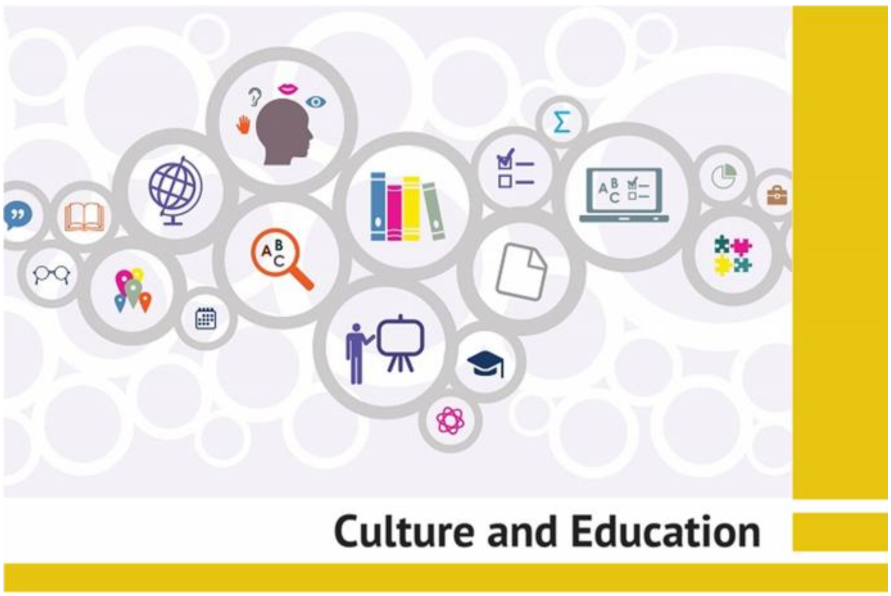
STUDY

Requested by the CULT committee

# Research for CULT Committee – Science and Scientific Literacy as an Educational Challenge




Policy Department for Structural and Cohesion Policies
Directorate-General for Internal Policies
PE 629.188 - March 2019

EN

# Research for CULT Committee – Science and Scientific Literacy as an Educational Challenge

**Abstract**

European societies are faced with emerging threats relating to the spread of disinformation and pseudo-science. In this context, fostering scientific literacy can provide people with tools to navigate and critically address the vast amounts of information exchanged in public debate, and support democratic processes. Building on a review of academic and policy literature, this study aims to enable Members of the European Parliament to form their opinions on the state of scientific literacy in the EU and on potential education policy responses to better prepare scientifically literate citizens.

This document was requested by the European Parliament's Committee on Culture and Education.


## AUTHORS

Hanna SIAROVA, Dalibor STERNADEL, Eszter SZŐNYI

Research manager: Pierre HERIARD
Project and publication assistance: Lyna PÄRT
Policy Department for Structural and Cohesion Policies, European Parliament



## LINGUISTIC VERSION

Original: EN

## ABOUT THE PUBLISHER

To contact the Policy Department or to subscribe to updates on our work for the CULT Committee please write to: Poldep-cohesion@ep.europa.eu

Manuscript completed in March 2019



This document is available on the internet in summary with option to download the full text at: http://bit.ly/2TCc6Uy

This document is available on the internet at:
http://www.europarl.europa.eu/RegData/etudes/STUD/2019/629188/IPOL_STU(2019)629188_EN.pdf

Further information on research for CULT by the Policy Department is available at:
https://research4committees.blog/cult/
Follow us on Twitter: @PolicyCULT

**Please use the following reference to cite this study**:
Siarova, H., Sternadel, D. & Szőnyi, E. 2019, Research for CULT Committee – Science and Scientific Literacy as an Educational Challenge, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels
**Please use the following reference for in-text citations**:
Siarova, Sternadel and Szőnyi (2019)

# CONTENTS

# LIST OF ABBREVIATIONS

| | |
|---|---|
| **AI** | Artificial Intelligence |
| **CoE** | Council of Europe |
| **EBSCO** | Elton B. Stephens Co. Educational Databases |
| **ERIC** | Education Resources Information Center |
| **EVS** | European Voluntary Service |
| **EU** | European Union |
| **GMO** | Genetically modified organism |
| **IEA** | International Association for the Evaluation of Educational Achievement |
| **ILSA** | International Large-Scale Assessment |
| **MEP** | Member of the European Parliament |
| **MMR** | Measles, mumps, and rubella |
| **OECD** | Organisation of Economic Co-operation and Development |
| **PIAAC** | Programme for the International Assessment of Adult Competencies |
| **PISA** | Programme for International Student Assessment |
| **STEM** | Science, Technology, Engeneering, Mathematics |
| **TIMSS** | Trends in International Mathematics and Science Study |

## LIST OF FIGURES



## LIST OF TABLES

# EXECUTIVE SUMMARY

Considering the emerging threats relating to the spread of misinformation and disinformation and the influence of anti-scientific movements, fostering scientific literacy among the population has never been more essential. Scientific literacy can provide tools to navigate and critically address the vast amounts of information exchanged in public debates, foster democratic political processes and ensure sustainable growth.

Building on a review of academic and policy literature, this study aims to enable Members of the European Parliament to form their opinions on the state of scientific literacy in the EU and on potential education policy responses to better prepare scientifically literate citizens.

## Key findings and recommendations

### Conceptualise scientific literacy in curriculum and competence frameworks

Scientific literacy goes beyond the mere knowledge of scientific content. It should be understood as the ability to engage critically with and make informed decisions about science-related issues. This broader approach to scientific literacy should be coherently integrated in curricula. Critical thinking and active engagement should be emphasised as important learning outcomes along with fundamental literacy, scientific knowledge and competences and a contextual understanding of science. Research highlights the need to integrate various elements of scientific literacy across educational levels and subject areas (such as science, history, geography, citizenship, health, and media education).

***Recommendations for EU action***

- The Commission should further support Member States by strengthening the evidence base for national reform and consider setting scientific literacy benchmarks for different levels of education in the context of the next strategic framework for European cooperation in education and training by 2030.
- The Commission should develop guidelines to support Member States in the implementation of the European Reference Framework of Key Competences for Lifelong Learning and further elaborate on what 'competence in science' implies for education policy and practice in relation to the concept of scientific literacy.

### Address the threats relating to the spread of misinformation and disinformation

Contemporary European societies are characterised by the vast amounts of information in circulation. The increased influence of, and democratisation in, the access to information and communication technology, the development of artificial intelligence and the growing mistrust towards traditional sources of information have created a favourable context for the spread of misinformation and disinformation on science-related issues. This phenomenon is reinforced by cognitive, social and technological biases relating to the functioning of social media platforms and online search engines. This situation poses major threats to public health, environmental protection, security and social cohesion. Responding to these threats implies strengthening media and scientific literacy in order to equip the general public with the tools to better detect, analyse and expose misinformation and disinformation and improve societal resilience[1].

***Recommendations for EU action***

- The Commission should promote educational approaches based on fact-checking and 'inoculation' to misinformation and disinformation to develop media and scientific literacy among the general public.
- The Commission should further disseminate scientific evidence on science-related issues and promote effective tools to detect, analyse and expose misinformation and disinformation.
- The Commission should promote interdisciplinary research and data collection[2] on the reach and impact of misinformation and disinformation on the general public and on the effectiveness of counter-measures.

### Support innovation and lifelong learning in science education

Fostering scientific literacy requires an integrated approach involving investment in, and re-thinking of, both formal and non-formal education. A number of important steps have been taken to promote scientific literacy through education across Europe. However, many education providers do not have the sufficient capacity to innovate and create inclusive and engaging learning environments to foster scientific literacy.

At the same time, the development of scientific literacy is not only a matter of youth development, it should be considered in a lifelong learning perspective, targeting both young and adult learners. Education policymakers need to support public and private initiatives to promote scientific literacy and critical thinking at all ages.

***Recommendations for EU action***

- The Commission should encourage participatory research and collaboration projects[3] aimed at the design, piloting and exchange of new teaching practices, and promote policy experimentation to develop scientific literacy among all citizens.
- The Commission should continue supporting and updating online databases of evidence-based good practices in education and training[4] to document effective approaches to teaching and learning scientific literacy.

### Develop adequate instruments for assessing scientific literacy

Measuring scientific literacy comprehensively proves to be a challenge. Existing tools are often focused on students' level of scientific knowledge and competences, leaving aside such elements as critical thinking and active engagement. The development of comprehensive assessment instruments could allow grasping scientific literacy more holistically and better understanding what educational approaches can help develop it.

---

[1] In line with the priorities of the Action Plan against Disinformation. See: European Commission and High Representative of the Union for Foreign Affairs and Security Policy, Joint Communication to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, Action Plan against Disinformation. Brussels, 5.12.2018, JOIN(2018) 36 final.

[2] For example, via the Erasmus+, Connecting Europe Facility and Horizon Europe programmes, and via Eurobarometer surveys.

[3] Via Erasmus+ and Horizon Europe.

[4] Such as the School Education Gateway. See: https://www.schooleducationgateway.eu/en/pub/index.htm.

***Recommendations for EU action***

- The Commission should use its funding programmes[5] to promote projects exploring and designing appropriate assessment instruments to better measure scientific literacy.
- The Commission should support the integration of an assessment of students' critical thinking and civic engagement skills into the OECD's PISA scientific literacy framework.
- The Commission should use Eurobarometer surveys to investigate the motivations and reactions of various groups on science-related social and policy issues and analyse the factors that shape scientific literacy.

### Build teachers' capacity to foster scientific literacy

Professional development opportunities for teachers need to better reflect the competences they require to develop scientifically literate students. National education systems should also develop schools' capacity to promote a collaborative learning culture that motivates teachers and builds their competences to adapt to the changing needs of learners and society.

***Recommendations for EU action***

- The Commission should promote professional development opportunities fostering innovative science teaching methods and cross-curricular approaches to science[6].
- The Commission should consider developing a detailed scientific literacy competence framework for educators[7] which would support teacher education providers to improve existing training programmes.

### Promote participatory research and open science

Designing effective education programmes to foster scientific literacy is a crucial step, but it is not sufficient. The promotion of open science can improve public access to scientific information and engage scientists into the public debate.

***Recommendations for EU action***

- The Commission should invest further in participative research projects to bring science closer to the public. Scientists should be incentivised to take a more active part in science-related public debates to combat the influence of misinformation and pseudo-science.
- The Commission should support the development of science consultation platforms[8] to ensure that robust and reliable scientific advice and evidence is rapidly available to the general public, journalists and policymakers.
- The EU Science Hub (Joint Research Centre, JRC[9]) should be further used for hosting science-related events between scientists, policymakers and the general public to promote evidence-based decisions and an informed democratic dialogue on various policy issues.

---

5 Such as Erasmus+ and Horizon Europe.
6 Such as the School Education Gateway's 'Teacher Academy'. See: https://www.schooleducationgateway.eu/en/pub/teacher_academy.htm.
7 Such as the Digital Competence Framework for Educators (DigCompEdu). See: https://ec.europa.eu/jrc/en/digcompedu.
8 Such as SciLine. See: https://www.sciline.org/.
9 See: https://ec.europa.eu/jrc/en.

# 1. INTRODUCTION

## 1.1. Context and aims of the review

Recent societal developments across Europe have been characterised by the spread of misinformation, disinformation and conspiracy theories, and the growth of anti-scientific movements such as climate change sceptics and anti-vaccines. In this context, scientific literacy and a critical approach to the validity, reliability and impact of information have become important tools for informed democratic processes. Many pressing policy issues facing European societies – such as health, energy, climate change, automation and sustainable development – raise clear scientific questions. They require an informed and critical view and scientifically literate citizens able to participate in the public debate around these challenges.

In light of these challenges, it is crucial to understand the state of scientific literacy in Europe and the evidence base on key approaches to strengthen it. Promoting scientific literacy in European societies is one of the solutions to combat the spread of misinformation and disinformation and ensure an evidence-informed democratic dialogue. This study aims to enable Members of the European Parliament (MEPs) to form their opinions on potential European Union (EU) education policy responses to foster scientific literacy in Europe.

The specific research questions this review aims to answer are:

- What is understood by the concept of scientific literacy?
- What is the level of scientific literacy among Europeans (to the extent evidence is available)?
- What are the current education policy approaches used to enhance scientific literacy among the population in different Member States?
- What key policy recommendations can be made to improve educational responses to foster scientific literacy among the EU population?

## 1.2. Note on terminology

There are various terms adopted in the literature to refer to scientific literacy. The most widely used terms are *scientific (and technological) literacy*, *scientific (and technological) culture*, *public understanding of science*, *scientific literacy* and *science literacy*. The usage of terms is strongly dependent on the language of publications. While French literature refers to the concept as '*culture scientifique*' (scientific culture), in the English language literature, the preferred terms are '*public understanding of science*' and '*scientific literacy*' (Laugksch, 2000). Although the emphasis and interpretation of each term can differ, their meaning is essentially the same (Holbrook and Rannikmae, 2009; UNESCO, 1993). A more detailed description of the evolution of the term and its conceptual understanding is provided in Chapter 2.

For sake of consistency and clarity, we only use '*scientific literacy*' throughout the report. This decision however does not exclude the dimension of culture emphasised in the term *scientific culture* (Las Vergnas, 2011), or the importance of technology in relation to science (highlighted in the terms *scientific and technological literacy*) (see Chapter 2 for more details). Furthermore, the concept of scientific literacy in this review refers to public understanding of science in its broad sense, encompassing both natural and social sciences. However, in most of the literature, when scientific literacy is used in terms of science education, it mainly refers to natural sciences.

## 1.3. Methodological approach

### 1.3.1. Review method

The main source of information for this report is secondary data. The review is narrative, but it followed a structured approach to the literature search on various elements of scientific literacy. The review draws on research using a range of approaches including meta-analyses, quantitative and qualitative research and analysing evidence from both small- and large-scale studies. It seeks to interpret different kinds of research while giving due weight to findings with a particularly strong evidence base.

To identify relevant research for analysis, we have applied both systematic and 'snowballing' search methods. A systematic search of peer-reviewed articles published since 2010 was carried out in EBSCO Educational Databases (including ERIC and the Teacher Reference Centre) and Google Scholar. Apart from online databases, we have performed targeted searches in specific thematic journals[10]. The following search keywords were used: 'scientific literacy'; 'scientific culture'; 'scientific curiosity', 'critical thinking'. Results were screened on the basis of the research questions. The review of academic literature was supplemented by an analysis of materials and studies produced by European and international government departments and agencies, international organisations (such as the OECD and the Council of Europe) and non-governmental organisations (so-called 'grey literature').

### 1.3.2. Scope of the analysis

The review primarily looks into sources published in English. Literature published in French was also included into the analysis on a less systematic basis. The review covers all EU Member States to the extent information on specific countries was available in English and French. In addition, evidence from non-EU countries was also included when relevant.

The report aims to provide a general overview of how educational policies can foster scientific literacy among the population, covering different levels of education (school education, higher education, non-formal education) to the extent possible. Due to the availability of the literature on the topic, school education policy and examples of interventions at this level have been included in the report more often.

## 1.4. Limitations

Our review of the literature, although not exhaustive, shows that the concept of scientific literacy has been more extensively researched in the US. However, the concept itself is highly relevant for the current European context, which is further outlined in the following chapters. One should also keep in mind the various terms used across countries to refer to the concept of 'scientific literacy' – e.g., '*culture scientifique*' in French. This can pose some limitations for the conceptual coherence of policy interventions aimed at developing scientific literacy in various Member States.

Moreover, although there is ample literature on the conceptual debate on scientific literacy and on potential educational interventions to teach science education, research on the effectiveness of possible policy solutions and educational practices to support scientific literacy in a broader sense is rather scarce.

[10] Such as the International Journal of Educational Research; Journal of Research in Science Teaching; International Journal of Science Education. We acknowledge the limitations of this selection and that other journals could potentially provide relevant evidence and be included in future reviews.

# 2. THE CONCEPT OF SCIENTIFIC LITERACY

**KEY FINDINGS**

- A comprehensive conceptualisation of scientific literacy can serve as a guiding framework for education policy in general and science education in particular.
- Scientific literacy goes beyond the mere knowledge of scientific content. It can be understood as the ability to engage with science-related issues and with the ideas of science in a social context as a reflective citizen. The concept of scientific literacy is composed of five key elements: 1) Fundamental literacy; 2) Scientific knowledge and competences; 3) Contextual scientific understanding; 4) Critical thinking; and 5) Agency/engagement.
- The development of scientific literacy is closely linked with other educational goals such as increasing the levels of media literacy, acquiring global competence and promoting competences for active citizenship. These should therefore be addressed in combination by various educational initiatives.

The way scientific literacy is understood has important implications for education policy and practice (Sjöström and Eilks, 2018). The OECD defines scientific literacy as "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (OECD, 2017, p. 22). The assessment and analytical framework of the OECD's 2015 edition of the Programme for International Student Assessment (PISA) identifies four distinct but interrelated aspects of scientific literacy: contexts (personal, local/national and global issues), knowledge (including content, procedural and epistemic knowledge), attitudes (including interest in science, valuing scientific approaches to enquiry and environmental awareness), and competences (OECD, 2017).

To understand and engage in critical discussions about science-related issues, the scientific literacy framework used in PISA 2015 highlights three domain-specific competences:

1) Explain phenomena scientifically (recognise, offer and evaluate explanations for a range of natural and technological phenomena).
2) Evaluate and design scientific enquiry (describe and appraise scientific investigations and propose ways of addressing questions scientifically).
3) Interpret data and evidence scientifically (analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions) (OECD, 2017).

The EU, by contrast, approaches scientific literacy as a key competence by itself, referring to it as a 'competence in science', defined as "the ability and willingness to explain the natural world by making use of the body of knowledge and methodology employed, including observation and experimentation, in order to identify questions and to draw evidence-based conclusions" (Council of the European Union, 2018a, p. 9). Science competence combines a set of specific knowledge, skills and attitudes, the acquisition of which is necessary to become a scientifically literate individual.

Even though the OECD and the EU apply different constructs when referring to scientific literacy, the essence of the concepts of scientific literacy and science competence is similar. They both highlight the importance of understanding the impact of science and human activity on the world and the responsibility of individual citizens.

This chapter further explores the meaning of scientific literacy, its role within education and beyond educational institutions. We clarify the definition of scientific literacy by providing a brief summary of the conceptual debate and by proposing a comprehensive framework of scientific literacy based on our review of the literature. The concepts of media literacy, citizenship education and global competence are also considered in relation to scientific literacy.

## 2.1. Conceptual debate

Despite the lack of one main definition in the literature, it is common to assume that scientific literacy is the desired outcome of science education; however, not limited to it. The evolution of the understanding of scientific literacy is a good illustration of how the goals of science education have evolved over time[11]. In the late 1950s, when the term first appeared in the English-language literature, the concept was used to emphasise the importance of science in society and that science education should "prepare the student to participate in human and civic affairs whatever his calling may be" (McCurdy, 1958, p. 366). In the 1960s, the goal of science education in the US focused on the need to promote science and produce future scientists and engineers (Yore, 2012).

In the 1970s and 1980s, scientific literacy was increasingly interpreted as science in its social context, referring to the "the ability [of scientifically literate individuals] to make decisions about science related social issues" (DeBoer, 2000, p. 588). At the same time, this approach to science education was criticised for not paying sufficient attention to the core of science as a discipline. In the following decade, the lack of consensus on the definition of scientific literacy resulted in the decreased usefulness of the term, mostly considered as a catchy slogan for science education (Bybee, 1997; DeBoer, 2000; Laugksch, 2000). The mainstream use of the concept in the 1990s referred to the acquisition of knowledge and meeting content-standards in science education, in relation to social contexts as well[12].

The most prevalent debate of the last two decades on the meaning of scientific literacy is the 'content versus societal relevance' dichotomy. Essentially, understanding the societal relevance of scientific literacy focuses on the usefulness of scientific understanding to society and real-life contexts. On the other hand, understanding scientific literacy based on content focuses on scientific knowledge and understanding itself. This duality is embedded in the literature on different models and classifications of scientific literacy, such as 'preparing future scientists' versus 'science for all' (Aikenhead, 2006), or Holbrook and Rannikmae's (2009) distinction of short-term and long-term views of scientific literacy (reflecting on the intentions of education policy and science education).

Roberts' (2007) classification of scientific literacy ('Vision I' and 'Vision II') – which is also based on the duality of content and context – proved to have a significant influence on the academic community. Some of the more recent conceptualisations of scientific literacy argue for scientific engagement (Liu, 2013; Yore, 2012) or 'engagement in socio-political action' (Hodson, 2010; Santos, 2009; Sjöström and Eilks, 2018) as a part of scientific literacy – often referred to as 'Vision III'.

Building on these visions, Liu (2013) suggests an "expanded notion" of scientific literacy, which provides a comprehensive summary of the debate and the characteristics of scientific literacy (see Table 1 below). This notion emphasises the importance of scientific knowledge, its relevance for particular contexts, critical thinking and engagement.

11 The following historical illustrations are mainly from the U.S. context, due to its dominance in relevant English language literature.

12 For a detailed historical review, see: Laugksch, 2000; DeBoer, 2000.

**Table 1. The expanded notion of scientific literacy**

| Relation to Roberts' (2007) visions | Emphasis | Content | Orientation |
|---|---|---|---|
| Vision I | Scientific content | Knowledge, skills, habit of mind, and disposition | Within science |
| Vision II | Science-technology societal issues | Knowledge in action, practical problem-solving, attitude, and professionalism | Science in relation to society |
| Vision III | Scientific engagement – social, cultural, political, and environmental issues | Critical thinking, communication, consensus building | Science within society |

Source: Based on Liu, 2013, p. 29.

The first category refers to 'Vision I', the approach that understands scientific literacy:

- within science, irrespective of external, contextual factors;
- as knowledge of the scientific content (concepts and practices), skills (referred to as habits of mind and dispositions in Table 1) for later application;
- as means to prepare students for a career in science, therefore;
- as needed only for those who intends to pursue such a career.

The second approach, developed from the idea of 'Vision II', comprehends scientific literacy:

- in relation to social contexts, acknowledging and considering non-scientific factors as well;
- as issues of scientific, technological and societal consideration;
- including elements such as problem-solving, analytical and interpretative skills;
- as means to prepare students to become informed and responsible citizens; therefore
- as needed for all students.

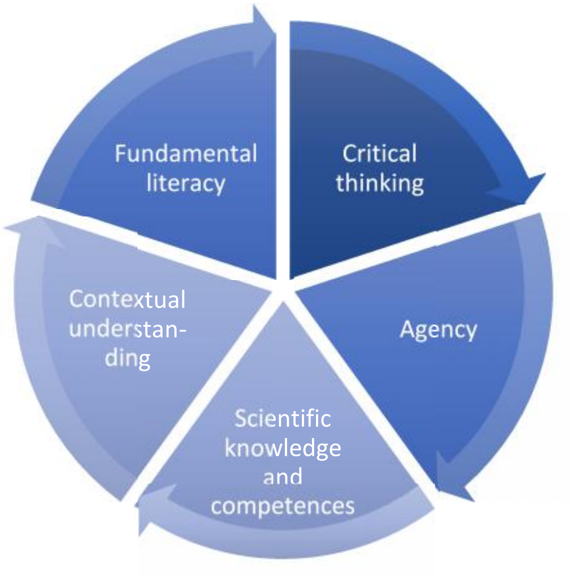
The third category, referred to as 'Vision III', is the broadest interpretation of scientific literacy, approaching it:

- as science embedded in society and societal issues;
- as action in the form of scientific engagement in various social, cultural, political, and environmental issues and contexts;
- involving key elements such as critical thinking and effective communication;
- as means to prepare students to become informed, responsible and active citizens; therefore
- as needed for all students.

## 2.2. A framework for scientific literacy

In light of the conceptual debate outlined above, we highlight five essential components that shape our understanding of scientific literacy, which build on and impact each other: fundamental literacy, scientific knowledge, contextual understanding of science, critical thinking and agency (or level of engagement) (see Figure 1 below).

**Figure 1. Framework for scientific literacy**




Source: PPMI

### 2.2.1. Fundamental literacy

Fundamental literacy means having the ability to read, write and count. This serves as a basis for learning more complex skills such as interpretation of texts (Yore et al., 2007). Also described by the notion of 'basic skills', fundamental literacy is vital for studying science and acquiring other competences.

Yore (2012) argues that the fundamental sense of scientific literacy includes a set of abilities and strategies, such as cognitive abilities, learning strategies, habits of mind and scientific language. It includes but also goes beyond writing and reading about scientific issues, incorporating both cognitive and affective levels of learning within literacy. The key components of fundamental literacy are described in Table 2 below.

**Table 2. Abilities and strategies of scientific literacy in its fundamental sense**

| | |
|---|---|
| **Cognitive and metacognitive abilities** | Cognitive learning, including:<br>- Having knowledge (about the world and about science processes – e.g. observation or measurement)<br>- Analytical reasoning, problem solving, critical evaluation of claims and evidence, etc.<br>- Planning and evaluation. |
| **Habits of mind** | Emotional dispositions (affective learning) towards science and technology.<br>- Beliefs (based on evidence and public evaluation)<br>- Values and attitudes (towards problems, solutions, and other points of view)<br>- Critical-response skills (e.g. scepticism) |
| **Scientific language** | Abilities in relation to scientific content, procedures and other related issues:<br>- To write, read, speak<br>- To present descriptions, arguments, explanations |

Source: Based on Yore, 2012, pp.12-15; and Yore et al., 2007, pp. 572-574.

Traditionally, science education has focused strongly on science knowledge rather than on basic skills, whereas some argue that a balanced concept of literacy considering both fundamental literacy and knowledge of science content is preferred (Norris and Phillips, 2003; Yore et al., 2007). These two aspects should interact and affect each other: without the acquisition of fundamental literacy, one struggles to become knowledgeable in the discipline of science, or risks to acquire a biased knowledge of science. At the same time, understanding a text about science (and engaging in scientific discourse) is not possible without the appropriate knowledge of scientific content, procedures and inquiry (Yore et al., 2007). Literacy in its fundamental sense also contributes to other general educational aims such as the development of higher-order skills or competences for democratic citizenship (Norris and Phillips, 2003).

### 2.2.2. Scientific knowledge and competences

A basic level of knowledge of scientific concepts, processes and their rationale is needed in order to understand science-related texts and to be able to interpret, analyse and critically evaluate them. In the OECD's scientific literacy framework used in PISA 2015, scientific knowledge is divided into content knowledge, procedural knowledge, and epistemic knowledge (OECD, 2017). Content knowledge is the knowledge of established scientific facts, concepts and theories. Procedural knowledge is related to the procedures of scientific inquiry, i.e. how scientific ideas are produced. Epistemic knowledge considers the understanding of the underlying rationale for these procedures and the justification for their use (OECD, 2017, p. 21).

To be able to understand and engage in critical discussions about science-related issues, knowledge needs to go in combination with specific set of competences: being able to explain phenomena scientifically, evaluate and design scientific enquiry, as well as interpret data and evidence (OECD, 2017).

### 2.2.3. Contextual understanding of science

Scientific literacy cannot be understood in today's society outside the context in which scientific issues arise. The contextual component of scientific literacy promotes 'scientific literacy for all' as an educational aim, placing the emphasis on everyday situations that are not only the concern of scientists (Sadler and Zeidler, 2009). Familiarising students with science outside of school is an important principle of science education (Sadler and Zeidler, 2009). This approach provides that students should be learning about the contexts as the subject of science education (e.g. about their personal energy consumption), instead of theoretical scientific content alone (Wickman et al., 2012).

Based on this approach, scientific literacy should contribute to the development of students as informed and responsible citizens (Sadler and Zeidler, 2009). A contextual perspective of scientific literacy takes into account non-scientific elements within a certain situation. It can therefore provide students with skills to be able to connect and integrate scientific and societal, technological, cultural, environmental or even political considerations (Sadler and Zeidler, 2009; Stuckey et al., 2013). Such a 'multiple perspective' approach is also an important characteristic of critical thinking.

### 2.2.4. Critical thinking

Critical thinking helps individuals make decisions and "evaluative judgements about what to believe or what to do" (Ford and Yore, 2012, p. 256). This decision is necessary to be able to form opinions and engage in debates on particular issues, as well as to engage in socio-political action. Scientifically literate individuals need to be critical thinkers in order to be able to evaluate information related to scientific issues, to assess the validity, reliability, authenticity and legitimacy of the source of information or the evidence provided, as well as to consider alternative perspectives or viewpoints (Vieira and Tenreiro-Vieira, 2016).

Critical thinking is an essential skill to be able to function as a responsible citizen in today's changing world. Itis widely recognised as an important '21st century skill' (Higgins, 2014). According to Silva (2009), '21st century skills' bring higher-order skills to the forefront as priority goals of education. The European Framework of Key Competences for Lifelong Learning (European Commission, 2018a) identifies critical thinking as one of the essential interpersonal, communicative and cognitive skills which are embedded throughout all key competences in a lifelong learning perspective. Digitalisation, the abundance of information in circulation and increased possibilities to access, share and express one's opinions, have made the question of validity and credibility extremely important. The uncertainty and complexity of science- or technology-related issues reinforces the growing significance of critical thinking (Vieira and Tenreiro-Vieira, 2016; Yore, 2012).

Critical thinking is crucial for educational goals and for citizenship education, but it is not enough in itself (Higgins, 2014). The other components of scientific literacy (such as fundamental literacy, scientific knowledge and competences, a contextual understanding of science, and agency) and other 21st century skills can help foster scientific literacy. Higgins (2014) suggests considering creative and inventive thinking as well as the capability to synthesise information along with critical thinking.

### 2.2.5. Agency/engagement

Taking action and engaging in society as a responsible citizen is a crucial characteristic of a scientifically literate individual. It builds on knowledge of science as well as the understanding of relevant social contexts. Scientific engagement encompasses both formal and non-formal spheres of education (Liu, 2013). It can take the form of both participation and action, which are among the attributes of being a responsible citizen in a democratic society.

This framework considers students (and ultimately all members of society) as agents. In this light, the different 'visions' referred to above represent varying levels of engagement (Roberts, 2007). Learning about scientific concepts, practices and their application (Vision I) can be considered as 'passive engagement'. Learning about the contexts in which students are faced with science-related issues (Vision II) requires 'active engagement' from students to "address complex and often controversial socioscientific issues, and formulate their own position concerning them" (Hodson, 2010, p. 199). The third 'vision' entails 'proactive engagement' where students learn to "prepare for, and engage in, socio-political actions that they believe will make a difference" (Hodson, 2010, p. 199).

The concept of 'critical scientific literacy' (Hodson, 2010) implies that students learn about potential socio-political actions and how to participate in those actions. Even though the development of scientific literacy, thus scientific engagement, is a continuous process which does not stop at the end of school education, Hodson (2010) suggests that students should be encouraged to take action and to experience action by "providing opportunities for them to do so and by giving examples of successful actions and interventions engaged in by others" (p. 202). The competences students acquire to become active agents in society contribute to making them better informed, responsible and active citizens based on democratic values. The concept of 'civic scientific literacy' identifies the aim of scientific literacy as the knowledge and competences required in today's society to function as a responsible citizen (Shen, 1975). This reflects how scientific literacy is intertwined with other relevant concepts such as citizenship education.

## 2.3. Scientific literacy and related concepts

Scientific literacy "promotes active participation in debate and seeking solutions on today's pressing issues facing the world" (Liu, 2013, p. 28). However, most global issues, such as climate change, science-related conspiracy theories and pseudoscience are not exclusively scientific issues; they overlap with other aspects. Scientific literacy is not an isolated concept but closely relates and interacts with media literacy, competences for active citizenship and global competence.

### 2.3.1. Media literacy

Media literacy can be defined as "the ability to access the media, understand and critically evaluate different aspects of the media and media contexts and to create communications in a variety of contexts" (European Commission, 2007). Being media literate supposes to have acquired a number of distinct but interrelated competences including the competences to access media skilfully, to analyse and evaluate media content and sources, create media content, reflect about one's media use, and to act and engage in citizenship through media (Hobbs, 2010).

Media literacy is closely related to scientific literacy and its key components, such as evaluation and analysis of content, content creation, and action/agency. For example, both scientific and media literacies are needed to be able to understand and critically engage with the applications of science in society and in various media formats (Carver et al., 2014; DeBoer, 2000; Norris and Phillips, 2003). As a dimension of individual agency based on democratic principles, media literacy can also support students' skills, confidence and attitudes to engage and participate in the public sphere by facilitating their active citizenship competences (McDougall et al., 2014).

McDougall et al. (2018a) note that media literacy and scientific literacy can be supported at primary and secondary education levels in the context of science education and in a cross-curricular approach. Media literacy can help students to "understand how media products are created, how scientific knowledge is incorporated into them, and to engage critically with science in the news" (McDougall et. al, 2018b, p. 24). Several teaching and learning practices can also facilitate the development of both scientific and media literacies such as game design and development, the creation of other audiovisual formats, and activities aimed to critically understand and deconstruct propaganda, disinformation and pseudo-scientific messages.

### 2.3.2. Competences for active citizenship

Active citizenship can be understood as "participation in civil society, community and/or political life, characterised by mutual respect and non-violence and in accordance with human rights and democracy" (Golubeva, 2018, p. 6). It promotes civic engagement at local, national and international levels, which is highly intertwined with the agency component of scientific literacy. The role of education is to support students in becoming engaged, informed and responsible citizens (De Coster et al., 2017, p. 3; (Council of Europe, 2010; European Commission, 2018a). The 'Competences for Democratic Culture' of the Council of Europe (2016) identified 20 competences including values, skills, attitudes, knowledge and critical understanding. The most vital of them for fostering engagement and active citizenship are the abilities to "manage change and uncertainty, think and act critically, deal with complexity, be creative and able to assess and take risks" (European Commission, 2018a, p. 56).

Scientific literacy "has implications for general literacy for citizenship and daily life – engaging in (participation) and with (confrontation/dialogue) science" (Yore, 2012, p. 15). Both scientific literacy and active citizenship can promote engagement, collaboration, creativity and innovation among other aspects (European Commission, 2015a). Furthermore, scientific literacy can reinforce active citizenship through fostering "fuller participation in the public debate about […] socio-scientific issues leading to informed solutions and sustainable actions" (Yore, 2012, p. 8).

### 2.3.3. Global competence

Scientific literacy can be also considered as an integral element of the so-called 'global competence', which the OECD argues to be "vital for individuals to thrive in a rapidly changing world and for societies to progress without leaving anyone behind" (OECD, 2018a). Globally competent individuals are expected to be able to examine issues of local, global and cultural significance, which refers to individuals' practices of effectively combining knowledge about the world and critical reasoning to form their opinions about certain global issues. The development of this dimension also requires media and scientific literacy (OECD, 2018a). Another key dimension of the global competence is the capacity and disposition of an individual to take constructive action towards sustainable and collective well-being, which is closely linked with the 'agency' dimension of scientific literacy.

# 3. THE ROLE OF SCIENTIFIC LITERACY IN THE 'MISINFORMATION AGE'

**KEY FINDINGS**

- Scientific literacy provides tools to comprehend the complexity of the world, navigate between information exchanged in the public debate and critically address misinformation.
- The spread of science-related misinformation can have dramatic consequences on the general public and on public health in particular.
- The public debates on climate change and vaccines are particularly prone to misconceptions, misinformation and disinformation campaigns that strive based on cognitive and social biases and can have dramatic societal consequences.
- Communicating the scientific consensus on contested issues in the public debate such as climate change or vaccines can be effective in influencing public perception, but the positive role of these messages is largely undermined when such messages are presented alongside misinformation.
- Inoculation theory suggests that people can be inoculated against misinformation in a similar way to biological immunisation against a virus. Educational practices based on inoculation can be useful to debunk misinformation and disinformation and develop people's ability to critically assess information.

## 3.1. The role of scientific literacy in the 'misinformation age'

### 3.1.1. Challenges of misinformation and disinformation

The advances in information and communication technology (ICT) have provided people with unlimited opportunities to access and share increasing amounts of information. At the same time, technology has given the capacity to anyone with an internet access to disseminate false information (mistakenly or not) on a global scale.

Considering the critical importance of scientific information in the policy-making process in areas like health or environmental protection, the spread of misinformation and disinformation poses major risks for societies' cohesion and security (Jeangene Vilmer et al., 2018; Marleau and Girling, 2017; Weiss, 2017). The knowledge, skills and attitudes provided by science and scientific literacy are all the more important to comprehend and navigate this complex environment.

Misinformation (false or misleading information) and disinformation (false or misleading information that is purposely spread to deceive people) are not new phenomena (Lazer et al., 2018). However, they have become especially difficult to apprehend with traditional tools with the growing influence of and democratisation in the access to ICT, internet and social media. The role and influence of historical and institutional 'bulwarks' against misinformation (such as democratic institutions and the media) have eroded. In addition, the functioning of social media and online search engines has increased tendencies to "reduce tolerance for alternative views, amplify attitudinal polarization, boost the likelihood of accepting ideologically compatible news, and increase closure to new information" (Lazer et al., 2018, p. 1095).

The growing mistrust towards traditional sources of information has created a favourable context for misinformation to attract a broad audience, in particular on issues related to politics and science. Recent evidence shows that misinformation on social media is diffused "significantly farther, faster, deeper, and more broadly than the truth" among all categories of information and reach far more people than "the truth" (Vosoughi et al., 2018, p. 359).

Strengthening media and scientific literacy throughout education can help provide a response to these threats in order to equip the general public with the tools to better detect, analyse and expose misinformation and disinformation and improve societal resilience[13].

### 3.1.2. Cognitive and social biases

Individuals have a 'natural' weakness for misinformation and disinformation, due to cognitive biases. These biases originate from the way the human brain process information on a daily basis and relate to the fact that one can only deal with a finite amount of information to avoid being overwhelmed (Ciampaglia and Menczer, 2018).

Confirmation bias illustrates people's tendency to favour information that confirms their existing beliefs and hypotheses, comfort them in their previous ideas and do not hurt their personal sensitivities. This bias relates to the concepts of selective exposure, by which individuals favour information that confirms their pre-existing attitudes, and desirability bias, suggesting that people are inclined to prefer information that pleases them (Lazer et al., 2018). Cook et al. (2017) argue that confirmation bias is "particularly strong when the underlying belief or attitude is also particularly strong" (p. 2). In such cases, any information provided is frequently dismissed uncritically.

Disconfirmation bias is a tendency to "ignore or reject information and assertions that challenge one's beliefs, even when they are demonstrably true" (McDougall et al., 2018b, pp. 32–33). This 'backfire effect' happens when people who are confronted with corrective evidence see their prior beliefs intensified instead of weakened by the confrontation (Cook et al., 2017).

Another psychological challenge related to the influence of misinformation is the false consensus, which describes a tendency to overestimate how common one's opinion is (Leviston et al., 2013). This social bias is reinforced by 'echo chambers' (or 'filter bubbles') within which one's existing beliefs are locked and reinforced through repetition and lack of free movement of alternative or competing ideas or beliefs, preventing one from engaging with ideas different from their own (Ciampaglia and Menczer, 2018; (McDougall et al., 2018b; Nikolov et al., 2015).

### 3.1.3. Technological biases

Technological biases related to the functioning of social media platforms and online search engines are also very influential in determining what information internet users are faced with. The digital revolution and the exponential development of social media platforms[14] has greatly increased the potential impact of misinformation and disinformation. The algorithms used by social media platforms and online search engines tend to personalise internet users' online experience, in order to offer them 'micro-targeted' engaging and relevant content tailored to their previous online history, preferences, and geographical location data. This phenomenon has led to the reinforcement of the users' cognitive and social biases (including confirmation and disconfirmation biases, filter bubbles and echo

[13] In line with the priorities of the Action Plan against Disinformation. See: European Commission and High Representative of the Union for Foreign Affairs and Security Policy, Joint Communication to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, Action Plan against Disinformation. Brussels, 5.12.2018, JOIN(2018) 36 final.

[14] As of January 2019, Facebook had more than 2.27 billion monthly active users, YouTube 1.8 billion, Instagram 1 billion, Twitter 326 million. Source: https://www.statista.com/. Accessed 14.01.2019

chambers), making them more vulnerable to misinformation and disinformation campaigns (Ciampaglia and Menczer, 2018; Jeangène Vilmer et al., 2018).

The spread of misinformation and disinformation on social media platforms has been amplified by the role of internet 'trolls' and 'bots'. 'Trolling' can be defined as a form of targeted online harassment often aimed to intimidate and silence victims based on their identity or political activity, or individuals critical of a specific country in the case of state-sponsored trolling (Nyst & Monaco, 2018). Social media 'bots'[15] are automated computer programmes impersonating humans that interact with other users through social media accounts (Ciampaglia and Menczer, 2018). Political activists, trolls and bots have notably had a substantial role in disseminating disinformation in the run-up to the 2016 US presidential campaign and in attempting to influence the 2017 French presidential campaign (Ferrara, 2017; Gaumont et al., 2018; Jeangène Vilmer et al., 2018; Nyst and Monaco, 2018).

Twitter bots exploit users' cognitive biases such as confirmation and popularity biases as well as Twitter's algorithmic biases by constructing filter bubbles around targeted vulnerable users and feeding them with disinformation (Ciampaglia & Menczer, 2018). Nonetheless, recent research results show that human behaviour contributes more to the spread of false information on Twitter than bots do, because of the greater likelihood of people to retweet falsity more than the truth (Vosoughi et al. 2018). In the next section, we will see that trolls and bots have also played a strategic influence in the context of scientific 'controversies' about climate change and vaccines.

## 3.2. The perils of misinformation for scientific consensus

Misinformation and disinformation are the manifestations of a more global epistemological crisis marked by the proliferation of 'fake science', historical revisionism and conspiracy theories (Jeangène Vilmer, 2018). Faced with attempts to question the legitimacy of the scientific consensus on various science-related issues, an uncritically deferential approach to science or its results would be contrary to its fundamental principles such as the importance to anticipate potential mistakes, incompetent or fraudulent applications of scientific methods. Nevertheless, in the 'misinformation age' science does provide "powerful antidotes to both error and deceit" (Helfand, 2016, p. 20) and remains by far the most effective means to navigate between information and misinformation. Recent public 'controversies' on climate change and vaccines have shown that the spread of misinformation can undermine public judgements about the level of scientific consensus and the perceived seriousness of certain scientific issues (Roozenbeek and van der Linden, 2018).

### 3.2.1. Addressing vaccine hesitancy

The spread of science-related misinformation can have potentially dramatic consequences on the general public and on public health in particular. Between 2000 and 2005 in South Africa, 330,00 deaths have been linked to the spread of a false information denying that HIV causes AIDS (Cook et al., 2017). In 2014, during the Ebola outbreak, myths circulating on social media suggested that some practices or products could prevent or cure the disease, leading to a worsening of the situation in affected regions[16] (Chou et al., 2018).

Evidence shows that vaccines are particularly prone to misconceptions, misinformation and disinformation (Broniatowski et al., 2018), as exemplified by the 'Wakefield case'[17], which wrongfully

---

15 In 2017, it was estimated that between 9% and 15% of active Twitter accounts were bots (Varol et al., 2017).

16 'Ebola: Experimental therapies and rumoured remedies' World Health Organization Media Centre, 15 August 2014. Available at: https://www.who.int/mediacentre/news/ebola/15-august-2014/en/. Accessed 07.01.2019.

17 In 1998, the publication of an article co-authored by the British physician Andrew Wakefield in the leading medical journal *The Lancet* suggested a connection between receipt of the measles-mumps-rubella (MMR) vaccine and autism. Despite

linked the measles-mumps-rubella (MMR) vaccine with autism. In Europe and the US, the decreased confidence in vaccine effectiveness and safety ('vaccine hesitancy'[18]), contrary to all scientific consensus, is causing great concern among the scientific community and public authorities (Black, 2016). The growing 'antivaccine' movement aims to legitimise a perceived debate about vaccine safety. Vaccine hesitancy has been accused to have directly contributed to decreased vaccination coverage rates and to an increase in vaccine-preventable diseases (Chou et al., 2018; Larson et al., 2018). In recent years this phenomenon has been connected to drops in vaccination rates and the increase of cases of mumps in the UK, measles outbreaks in the US to the resurgence and outbreaks of measles in Europe (Carrillo-Santisteve and Lopalco, 2012; Cook et al., 2017; Helfand, 2016; Larson et al., 2018).

The field of medicine and health-related news is most vulnerable to misinformation and disinformation campaigns, particularly on social media (Chou et al., 2018). Broniatowski et al. (2018) have shown that Twitter bots and trolls[19] have a significant impact on online communications about vaccination. These automated accounts were found to post vaccine-related content at significantly higher rates than the average Twitter user and to promote pro- and anti-vaccination arguments in order to create political discord and legitimise a supposed debate on vaccine effectiveness and safety (Broniatowski et al., 2018). This strategy is also used across a range of other controversial topics in other examples of state-sponsored trolling by generating a large number of social media posts and comments about a certain issue to create a false impression of popularity, majority opinion or artificial citizen-based grassroots debate – a technique known as 'astroturfing' (Jeangène Vilmer et al., 2018).

### 3.2.2. Facing climate change denial

As for vaccine hesitancy, promoters of disinformation on the causes and consequences of climate change (driven by concerns about their livelihood, their profits, or their religious beliefs) have aimed to create confusion on a topic that is overwhelmingly consensual within the scientific community (Cook et al., 2016)[20]. This stance suggests that there would be "two sides" to the issue of human-caused (anthropogenic) climate change and that both positions should be treated equally (McCright et al., 2016). While there is indeed much debate within the scientific community "about the details of climate models and their predictions, the calibration of proxies, the best tools to use to further the science, etc." (Helfand, 2016, p. 254), there is no controversy about the impact of human activity on the Earth's climate.

The media's willingness to provide equal weight to both sides of the 'climate debate' and the influence of political groups and lobbyists have led the general public to overestimate the number of climate change sceptics, and undermined the scientific consensus on the causes of climate change (Cook et al., 2017; Leviston et al., 2013). 'False balance' media coverage has been shown to decrease acceptance of

evidence published in 2004 that the article was a fraud, numerous studies published which have failed to show a link between the MMR vaccine and autism, full withdrawal of the article by *The Lancet*, and the fact that Wakefield was stripped of his ability to practice medicine in the UK by the General Medical Council in 2010, the controversy which followed the publication of the article has had (and continues to have) an enormous impact on public health (Helfand, 2016).

[18] Vaccine hesitancy is defined as "[a] delay in acceptance or refusal of vaccines despite availability of vaccine services" by the World Health Organization's Strategic Advisory Group of Experts on Immunization (SAGE) (WHO, Report of the SAGE Working Group on Vaccine Hesitancy, 2014; quoted in Larson et al., 2018, p. 6).

[19] This study particularly observed the activity of Russian troll accounts linked to the Internet Research Agency (IRA) – an organisation backed by the Russian government specialising in 'online influence operations' – who have also been accused to have interfered in the US political system during the run-up to the 2016 elections (Broniatowski et al., 2018). Although evidence of state-sponsored trolling has mostly been observed to originate from Russia in recent cases, multiple other countries have also been accused to engage in similar disinformation and digital harassment campaigns (Jeangène Vilmer et al., 2018; Nyst and Monaco, 2018).

[20] Around 97% of publishing scientists and relevant peer-reviewed articles that human activity has a direct impact on climate change (Cook et al., 2016).

scientific consensus on climate change, belief about the veracity of climate science, awareness of the consequences of climate change and support for greenhouse gas emission reductions (McCright et al., 2016). Leviston et al. (2013) showed that the debate on the existence and causes of climate change is subject to strong false consensus effects, where people largely overestimate the absence of consensus on the issue despite facts proving the opposite.

## 3.3. Effective educational approaches against misinformation

### 3.3.1. The challenges of fact-checking against misinformation

As shown by the impact of vaccine hesitancy, misinformation can have critical consequences on public health and safety and is often difficult to debunk. While addressing misconceptions in the classroom can be one of the most powerful ways to teach science (Cook et al., 2014), re-affirming the prominence of the consensus on crucial science-related public debates can be challenging (Lewandowsky and Oberauer, 2016). Fact checking (or 'debunking') does help and is an important response to the spread of misinformation and disinformation in the media. However, it is often "too little, too late" (Weiss, 2017, p. 427) to durably combat information manipulation and promote scientific evidence.

Communicating the scientific consensus on contested issues in the public debate such as climate change or vaccines can be effective in influencing the public perception on these issues (van der Linden et al., 2017). However, the positive role of messages presenting the scientific consensus is largely undermined when such messages are presented alongside misinformation (van der Linden et al., 2017). Research for example shows that due to the backfire effect, presenting the scientific consensus on the human causes of climate change may lead to opposite effects and reduce the acceptance of the perceived consensus on human-caused climate change among certain people, such as strong supporters of unregulated free markets (Cook and Lewandowsky, 2016). Alongside fact-checking, promoting critical thinking and scientific literacy among the general population is crucial.

### 3.3.2. Inoculation against misinformation

Faced with the limited effectiveness of fact-checking, inoculation theory can be a useful tool to develop people's ability to critically assess information. This approach suggests that people can be inoculated against misinformation such as against a virus (Banas and Rains, 2010). Inoculation can be used as a vaccine to 'neutralise' misinformation by being exposed to a 'weakened' version of the false information beforehand. Cook (2017) suggests an inoculation strategy based on three steps which can be adapted to an educational context: fact, myth and fallacy.

In the example of climate change, the 'Fact-Myth-Fallacy' approach starts from the explanation of a single climate science fact. For example, one can emphasise that human emissions are responsible for all of the increase of $CO_2$ in the air over the past two centuries. This statement of a proven scientific fact should then be followed by the presentation of a related myth, warning students that this is based on a false information: "volcanoes produce more $CO_2$ than humans". This exercise based on inoculation theory should be concluded by an explanation of the fallacy employed by the myth. Here, it should be underlined that while volcanoes do produce $CO_2$, these amounts are too small to account for the observed changes in the climate in recent centuries (Cook, 2017). Importantly, the process of deconstruction and debunking of misinformation should offer a factual alternative, a 'stickier fact' to debunk and replace existing fallacies based on science denial in the learners' mental model (Cook, 2015).

Inoculation approaches are more effective to strengthen people's resistance to misinformation than the simple promotion of accurate information and messages based on the scientific consensus without mentioning related misinformation (Cook et al., 2017). Inoculation can also reduce the influence of conspiracy theories by reinforcing sceptical attitudes towards conspiratorial claims. Cook et al. (2017) found that inoculation "neutralized the negative influence of misinformation on perceived consensus" about climate change (p. 15). If possible, when communicating about the scientific consensus on human-caused climate change, one should inform students (or the public) that "politically or economically motivated actors may seek to undermine the findings of climate science" and hence explain the nature and goals of disinformation campaigns (van der Linden et al., 2017, p. 6). Such forms of inoculation are also effective among individuals whose worldviews may "predispose" them to be sceptical about climate change, such as political conservatives and strong supporters of the free market (van der Linden et al., 2017).

### 3.3.3. Other approaches to tackle misinformation

Scientific evidence is often rejected because it is in conflict with people's worldviews, political or religious opinions, not only because they are misinformed (Lewandowsky and Oberauer, 2016). Evidence suggests that the general level of education, scientific knowledge and literacy "are only modestly predictive of the public's general attitudes toward and trust in science" (Lewandowsky and Oberauer, 2016, p. 218). Research findings from the US show that people with the highest degrees of scientific literacy were not the most concerned about climate change, but showed the greatest cultural polarisation on these issues along political lines (Kahan et al., 2012).

Providing information on the mechanisms and causes of a scientific phenomenon (such as global warming) can increase its understanding and acceptance (Ranney and Clark, 2016). Other approaches to address misinformation in education include misconception-based learning, learning based on the study of misinformation ('agnotology'), or learning from refutational texts (Cook et al., 2017). Research also suggests that educational games based on the principles of inoculation theory can be effective to reduce the perceived reliability and persuasiveness of disinformation campaigns (Roozenbeek and van der Linden, 2018).

Public actors such as scientists, journalists, politicians have a crucial role to promote scientific evidence and scientific literacy in the public debate. Their position, legitimacy and visibility give them the responsibility to be pro-active and ensure the effective dissemination of evidence-based information. These actors, as well as the general public, can help "inoculate each other to achieve societal immunity against misinformation" (van der Linden et al., 2017). In the US, the Association for the Advancement of Science (AAAS) has recently launched SciLine[21], a free service providing access to trustworthy scientific experts for journalists and other communicators working on and producing science-related issues. SciLine also offers freely accessible evidence-based, factual summaries of newsworthy scientific issues reviewed by experts designed to be quickly and easily scanned by journalists and others seeking scientifically derived information on science-related topics in the news. Recent examples include fact sheets and briefings on immunotherapy for cancer, carbon capture and storage or the role of climate in heat, fire and floods.

---

[21] See: https://www.sciline.org/. Accessed 15.01.2019.

# 4. SCIENTIFIC LITERACY IN EUROPE

**KEY FINDINGS**

- The comprehensive assessment of scientific literacy is limited by methodological challenges. International large-scale student assessments and public opinion surveys provide useful evidence on elements of scientific literacy, including scientific knowledge and competences, attitudes and motivation in learning about science, or perceived importance of specific science-related issues.
- PISA 2015 is the most comprehensive comparative assessment study measuring scientific literacy of 15-year olds to date. According to PISA 2015 results:
  - The average share of underachievers in science in the EU is 20.6%, while the target for 2020 is 15%.
  - There is a general pattern showing that countries from Northern and Western Europe generally perform better in science compared to Eastern and Southern countries.
  - Engagement of students in science-related activities outside of school is generally low.
  - Boys perform better in science than girls in most countries and are also more likely to engage in science-related activities in and outside schools.
- There is a general positive view on science- and technology-related issues in Europe. Engagement in action on science-related issues (e.g. fight climate change) is highest in Western and Northern European countries and lowest is certain Eastern European countries.
- More than 50% in all EU-28 countries say that they are confident in their ability to identify fake news online. Trust in all types of media sources is lower in Central and Eastern Europe.
- Younger people have more positive attitudes towards scientific issues, they are more likely to both use and trust online media sources, including online newspapers and podcasts.

Measuring scientific literacy comprehensively proves to be a challenge. Existing tools tend to assess only specific components of scientific literacy such as scientific knowledge and competences, leaving aside other important elements of scientific literacy such as critical thinking and agency (see Chapter 2). This is mainly due to the difficulty of defining specific and clear indicators for these elements. Nevertheless, analysis of existing large-scale assessment data as well as closer look into the public opinion surveys on societal issues requiring an understanding of science provides some initial insights about scientific literacy in Europe. This section explores large-scale assessment data on science performance and public opinion surveys measuring attitudes of the adult population towards science-related issues, using primarily the results of recent Eurobarometer reports. This section also provides reflections on what these data can tell about scientific literacy in contemporary European societies.

## 4.1. Measuring scientific literacy among students

Measuring scientific literacy among students is the objective of two main international large-scale assessments (ILSAs): the OECD's PISA and the IEA's Trends in International Mathematics and Science Study (TIMSS)[22]. While TIMSS focuses primarily on science curriculum standards, thus measuring the level of scientific knowledge of students, PISA attempts to capture the complexity of scientific literacy

[22] PISA and TIMSS measure student performance in natural sciences. When describing scientific literacy in relation to these assessments, we refer to natural sciences only. They also have different target groups: participants to PISA are 15-year-olds, while TIMSS cover grades 4 and 8.

by measuring students' knowledge, competences, contextual understanding of science and critical thinking. Furthermore, it explores students' attitudes, interest and motivation in learning science[23].

According to PISA data from 2015, the average share of underachievers in science is 20,6% in the EU, which does not yet meet the target of ET 2020, setting out to reduce underachievement in basic skills (including science, mathematics and reading) in Europe below 15% (European Commission, 2018b). Looking at the country level, Estonia, Finland and Slovenia have the highest share of students reaching the baseline proficiency level[24] (90% in Estonia and approximately 90% in Finland and Slovenia), while less than 70% of students reach baseline proficiency level in science in Romania, Bulgaria, Greece, Malta and Slovakia (OECD, 2016a).

PISA also measures attitudes concerning students' motivation and engagement in out-of-school activities related to science. The importance of motivation is based on its driving force for both learning and engagement in science (OECD, 2016a). The increase in motivation of students from 2006 to 2015 (in Ireland, Poland, Denmark, Spain, Sweden, and the UK) has led to their more active participation in science-related activities, while it decreased in Finland, Hungary and the Czech Republic (OECD, 2016a).

Regarding both elements of motivation – interest in and enjoyment of learning science and engagement in science-related activities[25] –, there are no clear patterns between EU countries (see Box 1 below).

**Box 1. Motivation to learn science and engagement in science among EU students**

**Interest in and enjoyment of learning of science:**

- Interest in learning science is highest in Portugal (78%) and Bulgaria (75%), and lowest in Austria (49%), Czech Republic (42%), and the Netherlands (46%).
- Enjoyment of learning science is highest in Estonia, Bulgaria, Lithuania, Portugal, Ireland and the United Kingdom; and lowest in the Netherlands, Slovenia and Czech Republic and also rather low in Hungary, Germany, Finland and Slovak Republic.
- These results show that the level of students' motivation does not follow the regional tendency in performance, as students in Western and Northern Europe are not more motivated to learn science than students in the Eastern and Southern Europe. Although the causes of this are unclear, the crucial role of individual teachers in motivating students is assumed to be part of the explanation.

**Engagement in science-related activities:**

- Engagement in science-related activities is rather low in the EU. It is higher in Eastern and Southern European countries such as Bulgaria, Cyprus, Estonia, Lithuania and Poland and lower in Western and Northern Member States such as Finland, Ireland, the Netherlands, Spain and Sweden[26].
- Low engagement in science-related activities could be explained by low level of interest in science or lack of opportunities. It can indicate that science education in school is not able to raise the interest of students sufficiently, or can also signify the increased importance of science education in school, as the primary scene for engagement in science-related activities. Students with higher level of science engagement also perform higher in science.

---

[23] In the latest round of PISA test (2018) the OECD included a 'global competence assessment', including an attempt to measure students' ability to 'spot fake news', which can be closely related to scientific literacy, if the information provided in the news requires an understanding of science (OECD, 2018a).

[24] The proficiency levels are defined in the PISA report (OECD, 2017, p. 44-45)

[25] Interest and enjoyment are related but different concepts. Interest describes the relation between students and learning science, while enjoyment is an emotion which can appear during the process of learning (see e.g. Schukajlow and Krug, 2014; Reeve, 1989)

[26] The pattern of engagement at country level show a contradictory tendency to performance, which is due to the fact that homework assigned to students is also considered in the activities related to science outside of school, and students reported to spend more time with homework in Eastern and Southern Europe. See: Azzolini et al., 2019.

- Boys, children of immigrant families and of highly educated parents are more likely to engage in science-related activities outside of school.
- Positive school climate encourages engagement in science as a school-level factor. Considering aspects of educational systems, "the level of selectivity is negatively correlated with science engagement" (Azzolini et al., 2019, p. 45).

Source: Azzolini et al., 2019; OECD, 2016a.

Differences in science performance by gender show a strong advantage of boys over girls. Among the EU-28 countries, the largest difference (at least 15 percentage points) in favour of boys is observed in Austria and Italy, and the strongest difference in favour of girls is in Finland and Bulgaria.

## 4.2. Attitudes of the public towards science-related issues

The general public's perception of science-related issues can notably be measured and analysed through public opinion surveys. While international large-scale assessments (ILSAs) among the adult population (such as the OECD's Programme for International Assessment of Adult Competence, PIAAC) do not measure scientific literacy per se[27], there are a number of public opinion surveys which explore public knowledge about, beliefs on, and attitudes towards, science-related topics. The most prevalent data collection on these issues in the EU Member States are Eurobarometer surveys. There are also other initiatives which include themes such as climate change or public knowledge about science in their surveys (e.g. European Social Survey, Pew Research Centre's surveys or World Values Survey[28]). However, the fact that Eurobarometer surveys gather self-reported data which does not automatically translate into scientific literacy constitutes an important limitation to fully understand the level of scientific literacy in the EU.

### 4.2.1. General attitudes towards science-related issues

Europeans generally have positive views on science- and technology-related issues[29]. More than 90% of the EU population believes climate change is a serious problem, and the gaps between different socio-demographic groups have narrowed on this question since 2015 (European Commission, 2017a). Similarly, 94% of Europeans consider environmental protection important for them, while 81% believe that environmental issues have a direct impact on their life and health (European Commission, 2017b). People also see the advancement of digital technologies as having a positive impact on the economy (75%), on society (64%) and on their quality of life (67%), and 68% consider robots and artificial intelligence "a good thing for society" (European Commission, 2017c, p. 65).

Considering the importance of media literacy in relation to scientific literacy, it is relevant to observe the level of trust towards sources of science-related and other information, trustworthiness of sources and identification of misinformation. Total trust in any media source is generally low across Europe: from 63%-70% of people tend to trust traditional media sources such as television or printed newspapers, while less than half of the respondents tend to have trust in online newspapers and news magazines (European Commission, 2018c). That is in line with the responses on source of environment-

[27] The Survey of Adult Skills conducted by PIAAC measures skills and competences, namely literacy, numeracy and problem-solving in technology-rich environments. See: http://www.oecd.org/skills/piaac/ Accessed: 12.01.2019.

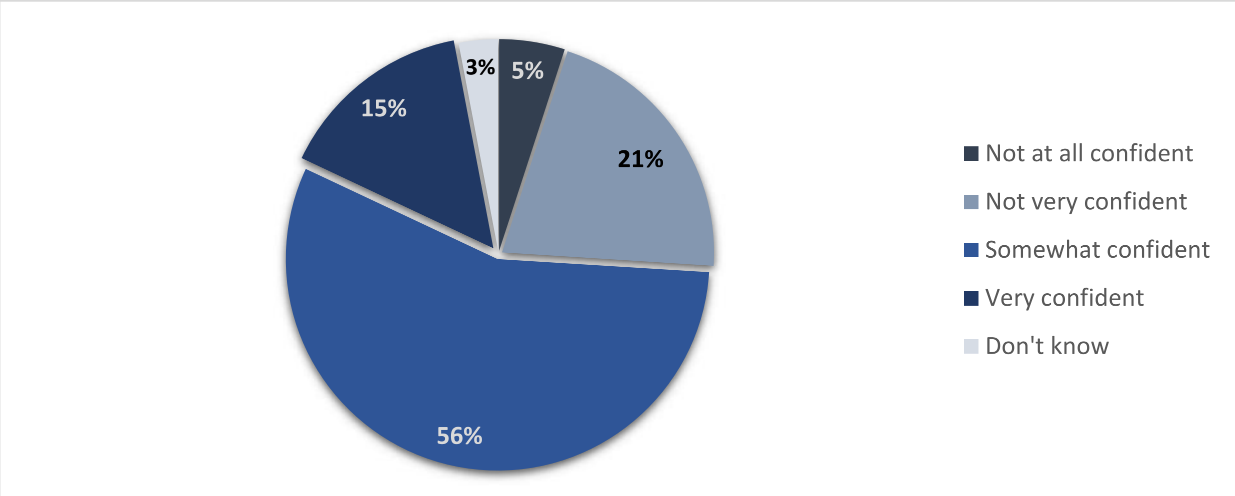
[28] The questionnaires, data and reports of the three surveys are available online. European Social Survey: https://www.europeansocialsurvey.org/; Paw Research Centre: http://www.pewresearch.org/; Word Values Survey: http://www.worldvaluessurvey.org/. Accessed: 12.01.2019.

[29] As these surveys are based on self-assessment and self-perception, they might show biased results based on aspects such as social desirability.

related information: 58% across Europe gain such information from television, while 42% from the internet and online social networks (European Commission, 2017b).

Less than two in ten Europeans feel very confident in identifying fake news, while altogether 71% feel at least somewhat confident (European Commission, 2018c) (see Figure 2 below). At the same time, only one third of the respondents have ever used fact checking websites to assess the trustworthiness of an online source, and 13% did not know about such websites at all (European Commission, 2017c). Regarding information on medical issues (such as antibiotics), Europeans see medical professionals as the most trustworthy source of information[30] (European Commission, 2018d). Accordingly, most respondents got information on the use of antibiotics from doctors (41%), another 28% from television news (or other programmes), while 24% of respondents got this information from television advertisements (European Commission, 2018d).

**Figure 2. Europeans' confidence in their ability to identify fake news**




Source: European Commission, 2018b[31].

### 4.2.2. Differences across EU Member States on attitudes towards science-related issues

**Attitudes towards science-related issues**

Respondents from Scandinavian and a number of Western European countries have the most positive and proactive attitudes towards science-related issues. Climate change is most likely to be considered one of the most serious problems of the world in Sweden (75%), the Netherlands (71%) and Denmark (69%). Similarly, a large majority of respondents in Sweden, the Netherlands and Luxemburg[32] say that they personally have responsibility for tackling climate change (European Commission, 2017a). In comparison to other countries, citizens of Western European and Scandinavian countries are more confident that they can successfully perform actions (personal efficacy) to fight climate change, such as reduce their energy consumption (in particular in France and Sweden). Respondents in these countries are also more likely to believe that such actions will have the desired outcome (outcome

30 86% of respondents mentioned doctors as a trustworthy source of medical information, 42% mentioned pharmacies and 21% mentioned hospitals (European Commission, 2018d).

31 The original question was "How confident are you that you are able to identify news or information that misrepresents reality or is even false?" (European Commission, 2018b, p. 15)

32 Sweden: 59%; the Netherlands: 55%; and Luxemburg: 44%.

expectancy), even though outcome expectancy is generally low across Europe (Poortinga et al., 2018)[33]. Respondents in Hungary, Slovenia, Estonia and the Czech Republic are the least confident in both cases. Personal efficacy and outcome expectancy are both essential elements for individuals or collectives to engage in science-related actions (Bandura, 1982; Hanss and Böhm, 2010)[34], which highlights the importance of psychological factors for scientific literacy.

Respondents in Central and Eastern European countries are less likely to be concerned about scientific and environment-related issues. As an example, in Croatia and Lithuania, 40-42% of respondents say that environment protection is very important, while it is most important for respondents in Sweden and Cyprus (European Commission, 2017b). Concern about climate change is lowest in Poland, Estonia, Lithuania and Ireland (less than 20% of respondents say they are concerned), and the feeling of personal responsibility in fighting climate change is the lowest in Hungary and the Czech Republic (Poortinga et al., 2018). Taking action against climate change is also lowest in Central and Eastern European countries, namely in Poland (30%), Bulgaria (21%) and Romania (20%), while it is highest in Sweden, Malta and Luxemburg (74-79%) (European Commission, 2017a).

Data further show that in Western and Northern European countries, respondents are more likely to trust both traditional and online media. Central and Eastern European countries are mostly under the EU average regarding trust in all media sources (expect for Latvia, Estonia and Slovenia), while in France, the UK, Spain and Italy the level of trust in certain types of news sources is below the EU average. Respondents in the Netherlands, Sweden and Denmark are most likely to consider information trustworthy on online social networks if it comes from a reliable source[35]. At the same time, reliability of the source is only considered for trustworthiness of stories on online social networks by 23% of respondents in Slovakia and Romania, and 18% in Croatia (European Commission, 2017c).

Even though more than 50% of respondents in all countries are at least somewhat confident in their abilities to identify misleading, false news, respondents are more likely to be confident in their ability to detect fake news in Northern and Western European countries, such as Denmark, Ireland, Finland, and the United Kingdom (79-87%). In Romania and Croatia this ratio is also above 75%. On the lower end of the scale, respondents are the least confident in their ability to identify fake news in Belgium (59% somewhat confident), Bulgaria (57%), Hungary (59%), Portugal (56%) and Spain (55%) (European Commission, 2018c).

**Trust of the public in science**

Various voices have highlighted the increasing mistrust faced by 'elites', including politicians, journalists and scientists[36]. On the other hand, recent Eurobarometer results show that Europeans consider medical professionals as some of the most trustworthy source of information (European Commission, 2018d).

One can look at the phenomenon of public trust towards science through the example of vaccines (see also section 3.2. above). The phenomenon of vaccine hesitancy is a significant and recurrent issue in

---

33 Twenty-three countries participated in Round 8 of the European Social Survey, among which only 18 are members of the European Union, therefore data from this source cannot be considered comprehensive for the European Union as a whole. Nevertheless, it shows important overarching trends

34 See Bandura (1982) on social cognitive theory and Hanss and Böhm (2010) on the relevance of self-efficacy for pro-environmental engagement.

35 Respondents were asked to identify the aspects based on which they consider a story published on online social networks trustworthy. The list includes elements such as a reliable source, the person who shared the story or the social network itself (European Commission, 2017c, p. 37).

36 'Fake News: Politicians, journalists, and scientists face mistrust together', Rafael Cereceda, Euronews, 15 February 2019. Available at: https://www.euronews.com/2019/02/15/fake-news-politicians-journalists-and-scientists-together-facing-mistrust. Accessed 22.02.2019.

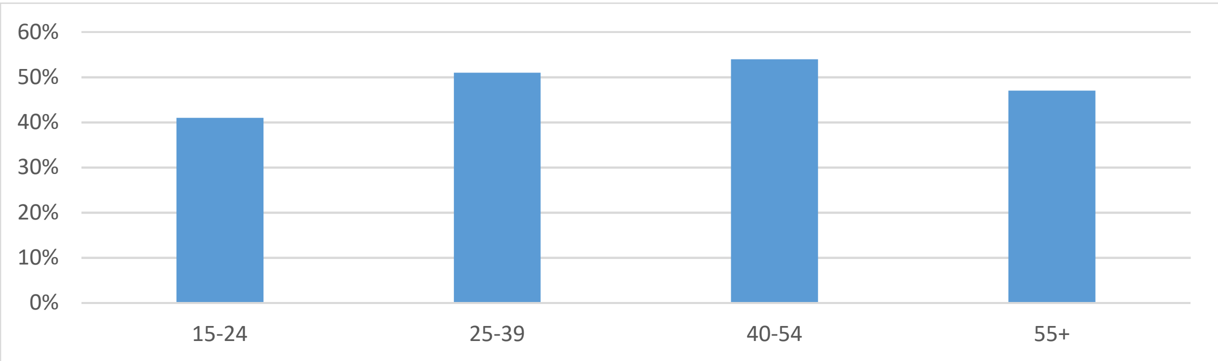
Europe, despite the generally wide coverage of vaccination in European countries (Larson et al., 2018; World Health Organization, 2016) (see also Section 3.2.1. above). Lack of vaccine confidence can be explained by a general distrust towards scientific institutions or towards science and scientific facts (among other reasons). Overall vaccine confidence[37] has increased since 2015 in Slovenia, Greece, Italy and the UK, while it has decreased in Poland. Respondents have more confidence in the safety of vaccines (since 2015), in Denmark, France, the Netherlands and Romania; and less confidence in Czech Republic, Finland and Sweden (Larson et al., 2018).

Evidence shows that there is a strong interest in science in France: 93% of the population wish to develop their knowledge in at least one scientific domain (CREDOC, 2013), and science remains highly respected within the public opinion (Huet, 2018). Nevertheless, recent controversies on nuclear energy, genetically modified organisms (GMOs) and vaccines have shown that the public debate can directly contribute to societal perception of science and technology (Chevallier-Le Guyader, 2015; Tournay, 2018). Developing scientific literacy among the general public should not absolve science and technologies of their potential risks or claim that any scientific innovation is good in itself. Scientific literacy and critical thinking in the public debate can help to reduce mistrust towards science (Helfand, 2016; Huet, 2018).

### 4.2.3. Scientific literacy by age and education level across Europe

Younger people (especially 15-39 year olds) trust online and printed news sources more than older respondents[38]. They are more likely to get information on environmental issues from online newspapers or social media and are also more confident in their ability to identify misleading information and disinformation online. This age group also has a more positive attitude towards new digital and technological developments, compared to other age groups. At the same time, younger people less often said they have taken personal action to fight climate change, compared to 40-54 year-olds (European Commission, 2017a) (see Figure 3 below).

**Figure 3. Personal action against climate change in the European Union[39], by age groups**




Source: European Commission, 2017a.

[37] Vaccine confidence was assessed by four aspects: perceived importance of vaccines for children, perceived safety of vaccines, perceived effectiveness of vaccines, and compatibility of vaccines with the respondent's religious beliefs. (Larson et al., 2018)

[38] Online sources include 'online newspapers and news magazines', 'video hosting websites and podcasts' and 'online social networks and messaging apps' (European Commission. 2018c).

[39] "Have you personally taken any action to fight climate change over the past six months?" (European Commission, 2017a, p. 35)

Based on Eurobarometer data, people with higher levels of education[40] are more likely to claim that they took personal action against climate change (especially in comparison with those left education at age 15 or earlier) (European Commission, 2017a). They are also more likely to say that the environment is personally important to them (European Commission, 2017b). Europeans with higher education levels have more positive attitudes towards technological changes, and they are more likely to trust online newspapers and news magazines than those who left school at the age of 15 (or earlier). Moreover, the reliability of a source (in deciding whether it is trustworthy or not) is more often important to the more educated (European Commission, 2017c). Those who remained in the education system longer are significantly more confident in their ability to identify 'fake news' (European Commission, 2018c).

[40] These surveys measure the level of education of individuals by marking when they left formal education (and not with standardised indicators of the final educational level reached or the number of years spent in education).

# 5. EDUCATIONAL POLICIES AND PRACTICES TO FOSTER SCIENTIFIC LITERACY

**KEY FINDINGS**

- Recent EU education and training policy documents rarely cite the concept of scientific literacy, but often refer to the importance of supporting fundamental literacy, critical thinking and civic engagement. Policy documents also emphasise the embeddedness of media, technological and environmental issues within science.
- Many EU countries support a contextualised understanding of scientific literacy in their school science curricula, with some references to other components of scientific literacy such as critical thinking and active engagement.
- Evidence shows contrasting results about the effectiveness of main types of teaching practices on students' cognitive and non-cognitive achievements. The use of more frequent 'teacher-directed instruction' in science is associated with higher performance, stronger epistemic beliefs, and a greater likeliness to pursue a science-related career, while 'inquiry-based teaching' is negatively associated with science performance but tends to support students' non-cognitive outcomes and positive attitudes towards science.
- Non-formal and informal learning environments can promote scientific literacy by raising the interest of the general public in science. The role of lifelong learning in the promotion of scientific literacy lies in engaging the public in science-related activities, ranging from events and initiatives of science centres, museums or civil society organisations, to involving the general public in the process of production of science.

Building on our conceptualisation of the notion of scientific literacy (Chapter 2), our analysis of the role of scientific literacy in the 'misinformation age' (Chapter 3), and an analysis of the level of scientific literacy in Europe (Chapter 4), this chapter focuses on various educational policies and practices to foster scientific literacy. We first provide an analysis of the extent to which scientific literacy is considered as a policy objective in recent EU policy documents, and at the level of Member States (through an analysis of examples of EU countries' school science curricula). The third section of this chapter discusses the role of school education in the promotion of scientific literacy through an analysis of the effectiveness of various teaching practices, conditions for their implementation, and suggestions for inter-disciplinary approaches for the teaching of science. The fourth and final section discusses the role of non-formal and informal education in the promotion of scientific literacy in a lifelong learning perspective.

## 5.1. EU policy in the area of scientific literacy

Even though EU countries are responsible for their own education systems, the EU supports, coordinates and supplements the actions of the Member States through various instruments such as recommendations, guiding frameworks and funding programmes. This section provides a brief review of recent EU policy documents and programmes that could help fostering scientific literacy in Europe.

### 5.1.1. Science and scientific literacy in EU policy documents

Scientific literacy has long been promoted as one of the key goals of education (e.g. European Commission, 1995), emphasising both its personal and collective benefits. At the same time, recent EU policy documents on education and training do not explicitly cite the concept of scientific literacy (e.g. Council of the European Union, 2018a; European Commission, 2018e, 2018f). While its components – fundamental literacy, scientific knowledge and competences, contextual understanding of science, critical thinking and engagement – are included to a various extent in various documents (e.g. in the 'Future of Learning' package[41]), only few connections are made between them or to science education.

Science competence is understood in the European Framework for Key Competences, as a process and a way of thinking involving an "understanding of the changes caused by human activity and responsibility as an individual citizen" (Council of the European Union, 2018a, p. 9). Science competence is needed "to cope with the wealth of information, data and interpretations offered" (European Commission, 2018a, p. 39). Science and science education are placed into wider socio-scientific contexts, such as technology and technological innovation, and environmental issues (European Commission, 2018a). Sustainable development and the implementation of the UN Sustainable Development Goals[42] (United Nations, 2017) through education is also prevalent in several EU policy documents.

Citizenship education (European Commission/EACEA/Eurydice, 2016; De Coster et al., 2017; Council of the European Union, 2018a), critical thinking, media literacy (Council of the European Union, 2016a, 2018a, 2018b; European Commission, 2018e, 2018f) and digital literacy (European Commission, 2018g) are among the most important educational objectives of EU policies. Promoting the active engagement of students (and citizens) in collective matters as well as responsible behaviour regarding social, political, environmental and technological issues indirectly foster scientific engagement and literacy. The integration of sustainability into civic competence shows how education for democratic citizenship and scientific literacy are intertwined, by emphasising individuals' personal responsibility "in deciding and contributing to the development of peaceful, inclusive and sustainable world" (European Commission, 2018a, p. 56).

Media literacy and critical thinking are both considered as essential underlying concepts in education, for all key competences (European Commission, 2018a). While media literacy and critical thinking are both well embedded in various policy documents considering citizenship education (Council of the European Union, 2016a; European Commission, 2018a), they are not sufficiently associated with science competence or scientific literacy. Scientific literacy appears in relation to digital literacy in the European Commission's 'Digital Education Action Plan' (European Commission, 2018g). The Action Plan includes actions and initiatives to strengthen open science and citizen science, in order to make science and technology more inclusive, ensuring participation for all citizens (see Section 5.4), as well as awareness-raising on the importance of digital skills and media literacy.

EU policies highlight the role of education in several aspects connected to scientific literacy, where science is understood as more than the accumulation of knowledge. They raise attention to the importance of enhancing media literacy and critical thinking skills, as well as support the promotion of active citizenship and engagement in non-scientific and in environmental issues. Most components of scientific literacy can be found in relevant EU policy on education, although they are not connected to each other or to a comprehensive understanding of scientific literacy.

---

41 The 'Future of Learning' package includes the Council Recommendation on Promoting Common Values, Inclusive Education, and the European Dimension of Teaching; the Council Recommendation on Key Competences for Lifelong Learning and the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Digital Action Plan. See: https://ec.europa.eu/commission/news/future-learning-package-2018-jan-17_en. Accessed 18.01.2019.

42 See: https://unstats.un.org/sdgs/. Accessed 18.01.2019.

### 5.1.2. EU programmes to support Member States in developing scientific literacy

One of the EU's tools to support Member States' efforts in reforming their education policies is the Erasmus+ programme[43], through which the Commission co-funds a variety of types of educational projects. Since 2014, 26 projects were funded under the Erasmus+ programme[44] related to the promotion of scientific literacy. Most of these projects[45] focus on more general perspectives of science education (instead of specific scientific topics), such as the development of teaching materials, capacity building for teachers, using innovative methods to enhance students' scientific literacy, or creating networks of educators and experts in order to share knowledge and successful practices. Additionally, most of these projects were implemented in general school education (including youth capacity building and exchange programmes), while others in higher education or adult education.

One of the explicit goals of the new proposal for the next Erasmus programme (2021-2027) [46] is to address issues and disciplines which will shape the future of Europe and which could "help people develop knowledge, skills and competences needed for the future" (European Commission, 2018h, p. 19). These include STEM, environment, climate change, clean energy, robotics, artificial intelligence, among others.

Horizon 2020, the biggest EU Research and Innovation programme, has an important role in supporting and promoting science across Europe. Two of the programme's specific objectives – 'spreading excellence and widening participation' and 'science within and for society' – directly relate to the promotion of scientific literacy in the EU[47].

The EU also supports European-wide platforms that aim to promote scientific literacy and develop science education through innovative teaching methods, sharing best practices and supporting teachers' capacity building. These include the *EU STEM Coalition*, which is a network for national STEM platforms aiming to "facilitate the exchange of best practices between national STEM platforms, and to support Member States in the development of new STEM strategies"[48]. The *Science on Stage Europe*[49] is an international platform for science teachers, also focusing on the exchange of best practices. *Scientix*[50], a project supported by the Horizon 2020 programme, serves as a platform where results and outputs of other projects supported by the EU has been gathered and made available for the public. It aims to support all STEM education stakeholders and promote collaboration between teachers, researchers and policy-makers in the field of STEM (Stone, 2014).

## 5.2. Scientific literacy in national curriculum frameworks

National strategies for education and national (or regional) science curricula are key guiding frameworks for shaping the teaching of scientific literacy at education system level. These documents affect all actors within primary and secondary education: local decision-makers, school leaders, teachers, teacher educators and students. In varying extent of details, curricula determine the goals, the core content and the expected learning outcomes of science education.

---

43 See: http://ec.europa.eu/programmes/erasmus-plus/about_en. Accessed 14.01.2019.
44 Among the projects under the category of 'Cooperation for innovation and the exchange of good practices'.
45 Information on the projects funded under the Erasmus+ programme (and its predecessor programmes) is available on the website of the European Commission: https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-projects-compendium/ Accessed 14.01.2019.
46 See: https://ec.europa.eu/programmes/erasmus-plus/news/commission-adopts-proposal-next-erasmus-programme-2021-2027_en Accessed 12.02.2019.
47 See further at: https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020. Accessed 12.18
48 See: http://www.stemcoalition.eu/about. Accessed 12.02.2019
49 See: https://www.science-on-stage.eu/. Accessed 12.02.2019
50 See: http://www.scientix.eu/. Accessed 12.02.2019.

This section provides insight into the extent to which scientific literacy is integrated in national science curricula in European countries[51]. Despite the growing interest in scientific literacy in the literature, curricular analysis focusing on scientific literacy in Europe is scarce. Moreover, the available research evidence varies significantly in terms of focus of the analyses – such as organisation of the curricula (e.g. Grajkowski et al., 2014) or specific teaching methods (e.g. SciLit, 2016) – and the level of education considered. The lack of consistent evidence prevents us to provide a general overview and conclusions on the integration of scientific literacy in curricula across Europe. Nevertheless, the examples presented in this section constitute a good indication of the main challenges regarding the promotion of scientific literacy through national curriculum.

### 5.2.1. The aims of science education

The specific objectives of science education, at both primary and secondary level, have an important impact on the curriculum (European Commission, 2011). Scientific literacy (or some of its specific components) is commonly considered the main goal of science education. The contextualisation of science subjects is the most prevalent element, while most curricula also include objectives relating to critical thinking, citizenship education, personal and collective responsibility (Nemzeti Alaptanterv, 2012; Vieira and Tenreiro-Vieira, 2016; SciLit, 2016; Marty et al., 2017).

Citizenship education, which incorporates several central elements of scientific literacy, is considered as an important aim of science education in Sweden, France and Hungary (at lower secondary school level) (Nemzeti Alaptanterv, 2012; Marty et al., 2017). These three countries focus on responsible and critical decision-making related to scientific and technological issues in society. Active citizenship is described in these countries as directing one's actions based on one's understanding of the surrounding environment and contexts (Nemzeti Alaptanterv, 2012) and as awareness of the consequences of the decisions of everyday life at both individual (e.g. health) and collective (e.g. environment) levels (Marty et al., 2017). A critical and constructive behaviour in order to solve sustainability issues are included in the Hungarian and Lithuanian science curricula (SciLit, 2016).

The relation between scientific literacy and citizenship education is focused on the understanding that in order to effectively promote scientific literacy in the curriculum, democratic decision-making has to be embedded "at its core" (Yacoubian, 2017). This means that the curriculum should refer to the advantages of scientific literacy in making decisions considering both the individual and the collective (societal) level, using specific contexts as examples. The Swedish and French curricula present good examples by highlighting possible decision-making contexts (personal health as individual and environment protection as collective benefits) where scientific literacy is necessary (Marty et al., 2017). This approach to the promotion of scientific literacy in the school curriculum reinforces the importance of scientific engagement and strengthens the role of active citizenship as a general educational aim.

### 5.2.2. Core content

The core content in the science curriculum designates specific subtopics[52] within one subject – in science education as an integrated subject area, or in physics, chemistry and biology education. Among the core contents of the curricula reviewed in this report, the traditional knowledge-based understanding of science takes a more significant and salient place than contextualised understanding

[51] Due to the limited availability of information, curricula considered here vary from primary school to lower secondary school.

[52] E.g. 'energy' or 'sound and wave motion in nature' in the Hungarian physics frame curriculum for lower secondary education (EMMI, 2012), or 'physics in everyday life' in the Swedish physics curriculum for lower secondary education (Marty et al., 2017).

of science (including references to engagement and critical thinking). Emphasis is usually placed on knowledge of concepts, processes and in some cases their applications.

In the case of the French and the Western-Swiss physics curricula, the core contents refer to specific topics of physics taught in physics education (e.g. 'Optics' or 'Electricity') (Marty et al., 2017). The focus is similarly on scientific knowledge in Portugal (Vieira and Tenreiro-Vieira, 2016) and Hungary, although in the latter case the relation of the environment and physics is also considered as a content area together with the aspects of responsibility towards the nature, environmental damages and individual or collective action (EMMI, 2012).

Unlike the previous examples, the core contents of the Swedish physics curriculum (for lower secondary school) are not organised in sub-topics of a certain subject area, but each topic contextualises science "to put more emphasis on the relationship between science, daily life and society" (Marty et al., 2017, p. 9). These topics include 'Physics in Nature and Society' and 'Physics in Everyday Life' among others. In the Lithuanian science curriculum for primary school, the organisation of scientific topics is similar to the Swedish example, with emphasising scientific communication and problem-solving, beside the understanding of scientific concepts and practical skills (SciLit, 2016).

### 5.2.3. Learning outcomes

Learning outcomes define the expectations towards students about the knowledge, skills and competences that they should acquire by the end of a certain learning process or period (Cedefop, 2017). A number of curriculum documents have either a significant or exclusive focus on scientific knowledge and understanding as well as certain skills for the application of such knowledge. For example, in the French physics curriculum, learning outcomes are not connected to any social context or everyday experiences of students (Marty et al., 2017). The situation is similar in the case of learning outcomes of the physics curriculum in Western-Switzerland.

The Polish, Lithuanian and Hungarian curricula place stronger emphasis on the knowledge of scientific concepts, processes and their application within learning outcomes (EMMI, 2012; SciLit, 2016). At the same time, some references to the world outside of school and the relation of science to that world appears in all of these cases. More specifically, the Hungarian curriculum expects that students are able to orientate within the scientific and technological world around them at the end of lower secondary school (EMMI, 2012). In the Polish curricula, there are objectives such as having respect for nature and raising the interest of students in science, however, the focus remains the traditional approach to scientific literacy (SciLit, 2016).

In the Swedish science curriculum, the primary expectations for students are very close to the components of scientific literacy considered in this report[53]. The main learning outcomes include a direct connection to the 'real world' and to technological, environmental issues. Most of the expectations are in the form of skills and competences (rather than knowledge), such as scientific reasoning, formulating opinions, consideration of the impact of human activity and technologies on the environment, multi-perspective thinking, as well as reference to actions contributing to sustainable development, thus scientific engagement (Marty et al., 2017).

### 5.2.4. Challenges of promoting scientific literacy through curriculum frameworks

Two main challenges can be identified based on limited evidence in relation to promoting scientific literacy through science education curricula. The first challenge considers the consistency of the three

[53] Fundamental literacy; scientific knowledge and competences; contextual understanding of science; critical thinking; and agency (see more in Chapter 2).

aspects of curricula discussed above: aims of science education, core contents and learning outcomes. While the contextualised view of science and the importance of 'scientific literacy for all' have proved to be a goal of science education in most countries, the organisation of the core contents and learning outcomes indicate a different emphasis on the connection of science to social contexts, critical thinking, active engagement, or responsible citizenship. The discrepancy between educational aims and expected learning outcomes signifies an inconsistency within the curricula, which makes it difficult to meet the determined aims.

However, the level of consistency varies between the countries. Among the countries considered here, Sweden has the most consistent curriculum[54], where learning outcomes (and core contents) meet the general aims of the education system (Marty et al., 2017). According to the different sections of the Swedish science curriculum, "students should be able to apply scientific concepts and scientific method to the surrounding world, to understand the consequences of science-related issues at both individual and collective levels, and to exercise their critical thinking and reasoning skills" (Marty et al., 2017, p. 12).

The second challenge lies in the nature of the curriculum as a policy document and in its implementation. The gap between the intended and the implemented curriculum (Marty et al., 2017) poses a challenge for science education, independent of the designated goals and learning outcomes. This challenge emphasises the importance of the role of teachers and teaching practices in formal education.

## 5.3. The role of school education in the promotion of the scientific literacy

### 5.3.1. The effectiveness of various science teaching practices

Teaching strategies, pedagogies and methodologies employed in education have a major impact on student performance, learning and motivation (Clavel et al., 2016; Echazarra et al., 2016; OECD, 2016b). Nevertheless, there is still considerable debate on the best methods for teaching science and fostering scientific literacy among learners. One of the main areas of divergence concerns the debate between inquiry-based teaching and teacher-directed approaches, and their effects on student cognitive and non-cognitive learning outcomes (Zhang, 2016; Jerrim et al., 2019).

**Inquiry-based and teacher-directed science instruction**

Inquiry-based science instruction aims to support students to acquire scientific knowledge by conducting their own scientific experiments and adopt a critical way of engaging with science (Mostafa et al., 2018). This type of teaching practice involves a wide range of student-initiated activities including authentic and problem-based learning activities, experimental procedures, experiments and hands-on activities, self-regulated learning sequences, discursive argumentation and communication with peers (Costa and Araújo, 2018). Inquiry-based teaching emphasise student autonomy, communication and collaboration by exposing students to scientific procedures in the classroom. In this sense, it allows students to direct their own teaching with the objective that they develop a genuine interest in science and its subjects (OECD, 2018b). Inquiry-based teaching is found to be particularly important in teaching physical and life sciences (OECD, 2016b), and has long been promoted at European level as bearing the potential to increase interest in science and stimulating teacher motivation (Rocard et al., 2007).

[54] Physics curriculum for lower secondary school.

Teacher-directed science instruction focuses on the role of teachers in transmitting knowledge and guiding students' learning. This type of instruction method aims to "provide a well-structured, clear and informative lesson on a topic" (OECD, 2016b, p. 63). Importantly, it should also involve explanations from teachers, classroom debates and questions from students. Teacher-directed instruction is found to be especially effective for teaching mathematics, for which it is the most frequently reported teaching approach among countries and economies participating in PISA (Echazarra et al., 2016).

Evidence shows contrasting results about the effectiveness of these two main types of teaching practices on students' cognitive and non-cognitive achievements. Results from PISA 2015 suggest that the use of more frequent teacher-directed instruction practices in science is associated with higher performance in science, stronger epistemic beliefs (understanding about the nature, organisation and sources of scientific knowledge) and a greater likeliness to pursue a science-related career (OECD, 2016b). These results are in line with previous research findings which showed the positive impact of direct instruction on students' learning outcomes compared to inquiry-based instruction (Alfieri et al., 2011; Stockard et al., 2018). Noticeably, PISA 2015 results demonstrate that the positive impact of teacher-directed instruction methods on science performance is not sensitive to students' socio-economic status, level of performance, the difficulty of science tasks, or the school context (Mostafa et al., 2018).

PISA 2015 findings also show a positive effect of teacher-directed instruction on students' attitudes and expectations such as enjoyment of and interest in science, epistemic beliefs in science and expectations to pursue a science career (Mostafa et al., 2018). It is also noticeable that students from socio-economically most disadvantaged schools who are more likely to be exposed to inquiry-based science instruction while students from most advantaged schools tend to report more frequent exposure to teacher-directed teaching (Mostafa et al., 2018).

On the other hand, results show that on average inquiry-based teaching is negatively associated with science performance, even after accounting for student and school socio-economic backgrounds (OECD, 2016b). Recent evidence also showed that frequent use of inquiry-based science teaching is not associated with higher performance in science examinations among students (Jerrim et al., 2019).

Nevertheless, results also suggest that inquiry-based teaching practices supports a number of students' science-related non-cognitive outcomes and attitudes. PISA 2015 results show a positive association between student-reported exposure to inquiry-based teaching and enjoyment of science, interest in broad science topics, participation in science-related activities, self-efficacy in science (belief that they can produce desired effects through their actions) and epistemic beliefs (Mostafa et al., 2018). Collaborative teaching strategies were also found to foster creativity, cooperation and leadership, deep learning and engagement (Echazarra et al., 2016).

**Adaptive instruction and teacher feedback**

Other common teaching practices in science include adaptive instruction and teacher feedback. Adaptive instruction is a pedagogical approach based on the adaptation of the structure and content of teaching to the perceived characteristics of students (including knowledge, skills and abilities) and the application of different teaching practices to various groups (Mostafa et al., 2018). Adaptive instruction is considered distinct from individualised and differentiated teaching since it is largely aimed at a "whole-class strategy" (Mostafa et al., 2018, p. 57). PISA 2015 findings show that adaptive teaching is associated to positive performance in science, as well as greater enjoyment of science than for all other teaching practices and stronger epistemic beliefs (Mostafa et al., 2018).

Teacher feedback in science classes is based on the provision of information to support students in their learning process and outcomes (OECD, 2016b). Feedback can include summative[55] and formative assessment information[56], approval or punishment. While teacher feedback in science lessons is associated with stronger attitudes towards science (including enjoyment of science and science epistemic beliefs), evidence shows that it is negatively associated with students' science performance (Mostafa et al., 2018). This can be explained by the fact that students who are facing learning difficulties are likely to attract more attention from teachers and therefore receive more feedback than others.

### 5.3.2. Conditions for effective use of various science teaching practices

Certain conditions are necessary for the successful use of different science teaching practices. All teaching practices are positively supported by a positive school environment, including support from teachers, good classroom management and teacher-student relations, and when students feel they belong at school (Echazarra et al., 2016). Inquiry-based teaching and learning is particularly sensitive to the school context. It benefits strongly from a positive disciplinary climate in science classes, a dedicated and positive school culture and school leadership, sufficient instruction time, support from parents and education authorities, a positive learning environment, adequate resources, equipment and personnel, and a sufficient level of guidance available to students (Mayer, 2004; Costa and Araújo, 2018; Mostafa et al., 2018). Most importantly, evidence shows that this type of teaching practice is highly dependent on the level of preparedness and experience of teachers. The strong focus on collaboration and students' autonomy in implementing enquiries render inquiry-based instruction highly dependent on teacher's specific skills, attitudes, capacity and willingness to implement it in their classrooms. In this type of instruction, "a lecture is more akin to a scripted performance; inquiry-based instruction is more about improvisation and adaptation" (Mostafa et al., 2018, p. 15).

The combination of various teaching practices can have positive effects on students' cognitive and non-cognitive outcomes. Mostafa et al. (2018) show that combining inquiry-based and teacher-directed science teaching could be beneficial for student performance in science "only if the interaction between [the two methods] is strongly and positively associated with science performance" to compensate for the observed negative effects of inquiry-based instruction on student cognitive outcomes (p. 53). A strict dichotomy between teacher-led or student-based instruction types bears the risk to represent a "too narrow a view of what really happens in the science classroom and its relation with students' achievement" (Costa and Araujo, 2018, p. 11). Evidence indeed suggests that most teaching strategies have a role to play to support student learning and can be used in in the classroom (Costa and Araujo, 2018; Echazarra et al., 2016).

### 5.3.3. Scientific literacy as a cross-curricular challenge

Several elements of scientific literacy considered in a broader sense can also be acquired in other disciplines than science education such as history, geography, citizenship education, or media education (European Commission, 2011). These include scientific engagement in social, cultural, political and environmental issues, critical thinking, communication, consensus building, and agency. For example, a number of pedagogical practices employed in the context of citizenship education – or in a cross-curricular manner in other subject areas – have the potential to support the development of

[55] Summative assessment can be defined as cumulative assessments of students' learning outcomes that intend to capture and report what a student has learned against certain standards (Dixson and Worrell, 2016). These assessment methods rely on an extrinsic motivation for students to certify their learning, represented by marks, transcripts and diplomas.

[56] Formative assessment can be defined as "activities undertaken by teachers — and by their students in assessing themselves— that provide information to be used as feedback to modify teaching and learning activities' (Black and Wiliam, 1998).

competences for both citizenship and scientific literacy. Citizenship education aims to support the development of 'civic' or 'citizenship competences' based on knowledge of democratic institutions, communication skills, democratic values, and attitudes fostering cultural diversity, respect for human rights, mutual respect and open-mindedness, openness to dialogue, empathy and critical thinking (European Commission, 2018b).

Evidence shows that innovative teaching and learning practices common in other subject areas than science education may also be used to foster students' competences in a cross-curricular manner. These may for example include collaborative learning approaches and reading strategies used in language classes (European Commission, 2018i). Interdisciplinary or cross-curricular approaches to teaching scientific literacy can also be provided through context-based science teaching. This approach refers to the diverse philosophical, historical, political or societal aspects of science, and aims to connect science and scientific understanding with students' everyday experiences (European Commission, 2011).

McDougall et al. (2018b) show that teaching media literacy may involve various pedagogical practices that can be combined with relevant approaches for fostering scientific literacy. For example, science education teaching practices inspired from journalism, where students create short news presentation to stimulate a debate in the classroom about media reporting of science-related topics, can develop students' media and scientific literacies (Marks et al., 2010). Another pedagogical practice which fosters both scientific and media literacies involves the use of advertising as a teaching and learning medium (Belova et al., 2016). Learning with and about advertising in the science classroom can effectively contribute to the development of students' scientific media literacy by promoting their critical thinking, consumer behaviour, attitude towards scientific issues such as the impact of cosmetics production on the environment (Belova and Eilks, 2015).

## 5.4. The role of lifelong learning, non-formal and informal learning in promoting scientific literacy

In today's fast-changing world characterised by massive amounts of information and misinformation in circulation, technological developments, and the continuously increasing relevance of social media, people need educational approaches that help them learn how to function responsibly and actively in their community or personal life in a lifelong perspective (European Commission, 2018b). These approaches surpass the formal context of education, in both temporal and spatial aspects (Norqvist and Leffler, 2017). Learning can take place in a variety of settings and contexts that are not limited to the school. The end of formal education also does not indicate the end of the learning period of life. Furthermore, some research suggests that learning dispositions towards science should be fostered starting from the early years when children are intrinsically curious about the world around them (see e.g., Marian and Jackson, 2017).

The objectives of non-formal and lifelong learning have long been considered as part of the EU's education, training and youth policy (e.g. Council of the European Union, 2018a, 2012). The EU is providing extensive support for projects related to non-formal and lifelong learning, first and foremost within the frame of the Erasmus+ programme.

Non-formal learning is characterised as a structured, organised way of learning outside of the official boundaries of school. It is usually voluntary and involves participatory methods (Eshach, 2007). It can be "carried out in addition to or instead of formal learning (…) [and] it is always more flexible" (Halonen and Aksela, 2018, p. 66). Non-formal education can offer students learning environments that are relevant for their everyday life, and it plays an important role in developing skills and competences that are essential for active citizenship as well as for becoming scientifically literate. Recent research results show that non-formal learning environments can promote scientific literacy by raising the interest of students in learning science and motivation for pursuing a career in the field of STEM (Halonen and Aksela, 2018). These learning environments for science education can include initiatives such as science camps (e.g. Halonen and Aksela, 2018; Lindner and Kubat, 2014).

Another common form of non-formal learning is youth work[57] (European Commission, 2015b), which is also connected to lifelong learning in many cases. Features of youth work through non-formal learning are applicable for scientific literacy as well. These include (European Commission, 2018b, p. 16-17):

- Learning by doing outside the formal school system
- Being dynamic, flexible and interdisciplinary
- Taking place on a voluntary basis in real-life situations, through peer interactions and participatory approaches
- Applying individualised and enjoyable ways of learning
- Being accessible to all irrespective of their background and formal educational level
- With a youth worker playing the role of a coach or mentor, and designed to support young people's personal and social development

Developing scientific literacy among general public can take variety of forms. In France, for instance, multiple activities and initiatives aimed at the promotion of 'scientific literacy for all' as a form of 'scientific popularisation' led to the institutionalisation of scientific literacy. These initiatives have flourished in the last four decades, from the creation of scientific and technical museums (such as the *Cité des sciences et de l'industrie* in Paris), scientific literacy centres across the country (*Centres de culture scientifique, technique et industrielle*), scientific popularisation journals, national events such as the *Fête de la science* (Science festival) or the *Nuit des étoiles* (Stars night), participatory projects, thematic clubs or networks, Fab Labs, Hackerspaces or Living Labs, and multiple civil society organisations active in the area of 'popular education' (Guyon and Maitte, 2008; Las Vergnas, 2015). These initiatives aim to establish a link between science and society and are targeting the general public (not only school students).

Las Vergnas (2015) notes that the multiple scientific literacy initiatives implemented in France since the 1970s have repeatedly called for 'science literacy for all' and for the creation of a stronger link between science and society. According to the author, organising a dialogue between scientists and 'lay people' is not sufficient to help plug this gap. On the other hand, he promotes the appropriation of knowledge and science by groups of people and organisations driven by the principles of 'popular education', empowering people by giving them the possibility to look for responses themselves (Las Vergnas, 2015).

The gap between the field of science and the general public motivated the creation of the initiatives of 'Open Science' and 'Citizen Science'. Open Science describes the transformation and opening up of scientific practice and research aimed to create a widely accessible 'science base' to produce, collaborate and share knowledge, for experts in scientific fields and the general public (Council of the European Union, 2016b; European Commission, 2016). This 'transformation of scientific practice' entails directing the focus of scientist and researchers from publishing towards dissemination and knowledge

[57] Youth work refers to "actions directed towards young people regarding activities where they take part voluntarily, designed for supporting their personal and social development through non-formal and informal learning" (Andersen et al., 2017, p. 8). Youth work can be for example arts or sports workshops at local level or activities in the context of the European Voluntary Service (EVS) at EU level. See more on youth work: https://ec.europa.eu/youth/policy/implementation/work_en (Accessed 20.02.2019).

sharing, "allowing [its] users [including the general public] to be producers of ideas, relations and services and in doing so enabling new working models, new social relationships and leading to a new modus operandi for science" (European Commission, 2016, p. 33).

Open Science aims to produce and share knowledge in a collaborative way, creating opportunities for Citizen Science. Citizen Science can be defined as "scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (Oxford English Dictionary, quoted in European Commission, 2016, p. 53). One of the goals of Citizen Science is to open up science for those who were excluded from the privileges of the science community, and in doing so provide access for the public to engage in scientific debates and activities, offering opportunities to learn about scientific methods, standards and values. Citizen Science can bring science, scientists and society closer, while enhancing scientific literacy among the adult population by increasing awareness of the societal relevance of scientific issues, and by "providing opportunities for learning, empowerment, enjoyment of nature, [and] social engagement" (Hecker et al., 2018, p. 7).

The role of lifelong learning in the promotion of scientific literacy lies in engaging the public in science-related activities, ranging from events and initiatives of science centres, museums or civil society organisation – as the French example shows –; to involving the general public in the process of the production of science.

# 6. CHALLENGES TO FOSTER SCIENTIFIC LITERACY IN EUROPE AND RECOMMENDATIONS FOR POLICY ACTION

**KEY RECOMMENDATIONS**

- There is a need for a holistic vision of scientific literacy in school curricula and competence frameworks for learners and teachers. Critical thinking and active engagement should be emphasised as important learning outcomes along with fundamental literacy, scientific knowledge and competences and a contextual understanding of science.
- The development of comprehensive assessment instruments is necessary in order to grasp scientific literacy more holistically and better understand what educational approaches can help develop it.
- Fostering scientific literacy requires an integrated approach involving investment in, and re-thinking of, both formal and non-formal education. Teaching scientific literacy needs to be integrated across educational levels and subject areas, targeting learners of all ages.
- Promoting educational approaches based on fact-checking and 'inoculation' to misinformation can help develop media and scientific literacy among the general public and address the threats of misinformation and disinformation.
- Professional development opportunities for teachers need to better reflect the competences they require to develop scientifically literate students through innovative science teaching methods and cross-curricular approaches to scientific literacy.
- The promotion of Open Science can improve public access to scientific information. It is also crucial to incentivise scientists to take a more active part in science-related public debates to combat the influence of misinformation and pseudo-science.

This chapter provides a summary of remaining and future challenges for the EU and its Member States to foster scientific literacy among the population. It discusses challenges which are not yet adequately addressed in policy, as our analysis of the literature has shown. It argues for the need of an integrated policy approach to develop a scientifically literate population by improving the provision of both formal and non-formal education in relation to scientific literacy accessible to learners of all ages and making science more accessible to the general public.  Based on these challenges, we also outline key areas for potential policy responses and EU action.

## 6.1. Better conceptualising scientific literacy in curriculum and competence frameworks

Scientific literacy goes beyond the mere acquisition of scientific knowledge. It includes the ability to think scientifically, apply knowledge in practice, critically assess information and actively engage in an informed democratic dialogue using valid scientific evidence and scientific tools for reasoning. This extended understanding of scientific literacy has been widely taken up by recent EU and national education policy strategies. The EU's recent 'Future of Learning' package[58] refers to all key elements of scientific literacy identified by this review and calls Member States to integrate them into their national curricula. However, this approach does not explicitly recognise the inter-related nature of the core

[58] Including the Council Recommendation on Key Competences for Lifelong Learning (Council of the EU, 2018) and the Commission's Digital Education Action Plan (European Commission, 2018f).

elements of scientific literacy and the need for cross-curricular approaches. By contrast, science education is still seen as the key discipline to develop scientific literacy in the EU.

Similarly, our review of available national curriculum frameworks in Europe demonstrates that the importance of scientific literacy is generally recognised. However, the way it is conceptualised and defined in terms of expected learning outcomes varies significantly across countries. In many cases, scientific literacy merely refers to the acquisition of scientific knowledge and its application, failing to grasp other key dimensions of scientific literacy, such as critical thinking and active civic engagement. All elements of scientific literacy should be integrated in curricula and fostered across educational levels and academic disciplines (such as science, history, citizenship, health, media education).

#### Recommendations for EU action

- While Member States are primarily responsible for their own education systems, the Commission should further support them by strengthening the evidence base for reform. The Commission should consider setting scientific literacy benchmarks for different levels of education for the next programming period.
- Considering the fragmented understanding of scientific literacy across national curricula, the Commission should develop coherent guidelines to support Member States in the implementation of the 2018 European Reference Framework of Key Competences for Lifelong Learning. The guidelines could further elaborate on what 'competence in science' implies in relation to scientific literacy, recognise the inter-relatedness of its key elements, highlight its cross-curricular nature and specify expected learning outcomes to guide Member States in reforming their national curriculum frameworks.

## 6.2. Addressing the threats relating to the spread of misinformation and disinformation

Today's information society is characterised by the vast amounts of information in circulation. The increased influence of, and democratisation in, the access to information and communication technology and the growing mistrust towards traditional sources of information have created a favourable context for the spread of misinformation and disinformation on science-related issues. This phenomenon is reinforced by cognitive, social and technological biases relating to the functioning of social media platforms and online search engines. This situation poses major threats to public health, environmental protection, security and social cohesion. Strengthening media and scientific literacy can help respond to these threats more effectively and equip the general public with the tools to better detect, analyse and expose misinformation and disinformation and improve societal resilience[59].

Coherent efforts are also needed in other related policy fields to tackle the challenges of disinformation. For example, there is a need to reinforce the economic model and the credibility of traditional media

[59] In line with the priorities of the Action Plan against Disinformation. See: European Commission and High Representative of the Union for Foreign Affairs and Security Policy, Joint Communication to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, Action Plan against Disinformation. Brussels, 5.12.2018, JOIN(2018) 36 final.

as well as use the potential of innovative approaches (such as artificial intelligence, deep learning[60] and blockchain technology[61]) to enhance information traceability.

### Recommendations for EU action

- The Commission should promote educational approaches based on fact-checking and 'inoculation' to misinformation and disinformation (such as the Fact-Myth-Fallacy strategy) to develop media and scientific literacy among the general public.
- The Commission should make the full use of its research and innovation programmes to explore the potential of emerging technologies that can help preserve the integrity of content, validate the reliability of information and enable its transparency and traceability.
- The Commission should promote interdisciplinary research and data collection[62] on the reach and impact of misinformation and disinformation on the general public and on the effectiveness of counter-measures.
- The Commission should further disseminate scientific evidence on science-related issues and promote effective tools to detect, analyse and expose misinformation and disinformation.
- The Commission should further support various initiatives, including through the Erasmus+ programme, on internet safety and education for digital and medial literacy. The Commission should also encourage awareness raising activities on disinformation and collaboration between fact-checking and civil society organisations and schools in provision and developing of relevant education materials.

## 6.3. Supporting innovation and lifelong learning in education for scientific literacy

Fostering scientific literacy requires an integrated approach involving investment in, and re-thinking of, both formal and non-formal education. A number of important steps have already been taken to promote scientific literacy through education across Europe. However, many education providers do not have the sufficient capacity to innovate and create inclusive and engaging learning environments to foster scientific literacy.

The development of scientific literacy and critical thinking should be considered in a lifelong learning perspective targeting both young and adult learners. Fostering learning dispositions towards science from early years can help boost young people's engagement with science at later stages of education.

At the same time, it is important to promote scientific literacy among the adult population. Recent Eurobarometer survey results suggest that people with lower levels of education tend to be less concerned about important science-related issues such as climate change, and more vulnerable to

---

60 For example, the company Fabula AI, created with support from the European Research Council (ERC), has developed (and patented) Geometric Deep Learning, an AI technology able to learn from social networks and deliver unbiased authenticity scores for any piece of news, in any language to quickly and accurately spot fake news. See: https://erc.europa.eu/news/erc-proof-concept-grant-examples-research-projects-1-round#a-step-closer-to-automated-fake-news-detection; and https://fabula.ai/. Accessed 13.02.2019.

61 The European Commission Communication 'Tackling online disinformation: a European Approach' (COM/2018/236 final) further points out that 'innovative technologies, such as blockchain, can help preserve the integrity of content, validate the reliability of information and/or its sources, enable transparency and traceability, and promote trust in news displayed on the Internet. This could be combined with the use of trustworthy electronic identification, authentication and verified pseudonyms'.

62 For example, via the Erasmus+ programme, the Connecting Europe Facility programme, the future Horizon Europe programme and Eurobarometer surveys.

disinformation. A variety of public and private initiatives to promote science or critical thinking among adult population are available across Europe, such as courses and programmes, scientific and technical museums, scientific literacy centres, scientific popularisation journals, science festivals, participatory projects, Fab Labs, Hackerspaces or Living Labs, thematic clubs or networks. Policy makers should consistently support such initiatives and ensure that they are accessible to socio-economically disadvantaged groups.

**Recommendations for EU action**

- The Commission should encourage the collaboration of various stakeholders through Erasmus+ and Horizon 2020/Horizon Europe projects aimed at the design, piloting and exchange of new teaching practices to develop scientific literacy among all citizens. Projects should also promote policy experimentation that will enable mainstreaming innovative practices across the system.
- The Commission should continue supporting and updating online databases of evidence-based good practices in education and training (such as the School Education Gateway[63]) to document effective approaches to teaching scientific literacy. It should also continue harmonising multiple storages of good practices created through a variety of EU-funded projects into one coherent database and ensure that rigorous research evidence is available to demonstrate their effectiveness.

## 6.4. Developing adequate instruments for assessing scientific literacy

The available literature highlights that simply conveying facts is not enough to change someone's belief in misinformation on science-related issues and that knowledge of facts does not necessarily translate in scientific literacy (see Chapter 3). Research is still needed to better understand how children and adults develop scientific knowledge and competences, how this can be promoted and whether the basic scientific literacy provided in science education at primary and secondary level can provide a foundation for lifelong learning.

Measuring scientific literacy comprehensively proves to be a challenge. Existing tools are often focused on students' level of scientific knowledge and competences, leaving aside such elements as critical thinking and active engagement. The development of comprehensive assessment instruments could allow grasping scientific literacy more holistically and better understanding what educational approaches can help develop it.

**Recommendations for EU action**

- The Commission should use its existing research funding programmes (such as Horizon 2020/Horizon Europe) to fund projects exploring appropriate assessment instruments to better measure scientific literacy. Such projects should be multi-dimensional (covering different types of assessment) and involve the collaboration of various stakeholders including researchers, scientists, educators and businesses engaged in the design of digital assessment tools.
- The Commission should support the integration of an assessment of students' critical thinking and civic engagement skills into the OECD's PISA scientific literacy framework.

[63] Available at: https://www.schooleducationgateway.eu. Accessed 18.01.2019.

- The Commission should further use Eurobarometer surveys and qualitative studies to investigate the in-depth motivations and reactions of various groups on social and policy issues requiring scientific literacy and analyse more in-depth the factors that shape the nature of scientific thinking among various social groups.

## 6.5. Building teachers' capacity to foster scientific literacy

In order to educate scientifically literate students, one needs scientifically literate teachers. Effective implementation of innovative science teaching practices (e.g. inquiry-based science teaching, integrated science teaching practices and lessons outside of school walls) depend on teachers' capacity. Relevant training and professional development opportunities for teachers should equip them with the necessary competences to develop scientifically literate students.

National education systems should also develop schools' capacity to promote a collaborative learning culture that motivates teachers and builds their competences to adapt to the changing needs of learners and society.

### Recommendations for EU action

- The Commission should raise awareness on and use the instruments at its disposal to provide various professional development opportunities for the promotion of innovative science teaching methods and cross-curricular approaches to science. A potential space for such opportunities is the 'Teacher Academy' hosted by the School Education Gateway[64]. The Commission should also continue promoting peer-learning and knowledge exchange practices through Erasmus+ opportunities.
- The Commission should consider developing and promoting a detailed science competence framework for educators[65]. This would provide a coherent framework for national teacher education providers to develop comprehensive teacher education programmes (at both initial teacher education and continuous professional development levels) to prepare teachers to foster scientific literacy.

## 6.6. Promoting participatory research and Open Science

Designing effective education programmes to foster scientific literacy is a crucial step, but it is not sufficient to build a scientifically literate population. The promotion of Open Science can improve public access to scientific information and engage scientists into the public debate. Additionally, it is important to create stronger links between science and society and increase public trust in science by engaging the general public in scientific activities and participatory research (Citizen Science).

### Recommendations for EU action

- The Commission should further invest in participative research projects based on the principles of Open Science to bring science closer to the public. Scientists should be incentivised to take a more active part in science-related public debates, as well as education activities at schools, to combat the influence of misinformation and pseudo-science.

---

64 See: https://www.schooleducationgateway.eu/en/pub/teacher_academy.htm. Accessed 18.01.2019.

65 Similar to the Digital Competence Framework for Educators (DigCompEdu). See: https://ec.europa.eu/jrc/en/digcompedu. Accessed 18.01.2019.

- The European Commission should promote and finance the development and maintenance of science consultation platforms (such as SciLine[66]) to ensure that robust and reliable scientific advice and evidence is rapidly available to media and policymakers.
- The EU Science Hub (or Joint Research Centre, JRC[67]) should be further used for hosting science-related events and discussions between scientists, policy makers and general public to promote evidence-based decisions and informed democratic dialogue on various policy issues. General public should be encouraged to take active part in science-related events and discussions (either through EU Science Hub or other platforms).

[66] See: https://www.sciline.org/. Accessed 18.01.2019.
[67] See: https://ec.europa.eu/jrc/en. Accessed 18.01.2019.

## REFERENCES


- Aikenhead, G.S., 2006. Science education for everyday life: Evidence-based practice. Teachers College Press., New York.
- Alfieri, L., Brooks, P.J., Aldrich, N.J., Tenenbaum, H.R., 2011. Does discovery-based instruction enhance learning? Journal of Educational Psychology 103, 1–18. https://doi.org/10.1037/a0021017
- Andersen T., Hougaard, K. F., Nindl, S., Hill-Dixon, A. 2017. Taking the future into their own hands: Youth work and entrepreneurial learning. Final report. Luxembourg: Publications Office of the European Union.
- Azzolini, D., Bazoli, N., Lievore, I., Schizzerotto, A., Vergolini, L., 2019. Beyond Achievement: A comparative look into 15-year-olds' school engagement, effort and perseverance in the European Union. Luxembourg: Publications Office of the European Union.
- Banas, J.A., Rains, S.A., 2010. A Meta-Analysis of Research on Inoculation Theory. Communication Monographs 77, 281–311. https://doi.org/10.1080/03637751003758193
- Bandura, A., 1982. Self-Efficacy Mechanism in Human Agency. American psychologist 37, 122–147.
- Belova, N., Affeldt, F., Eilks, I., 2016. Using advertising as a teaching and learning medium in the science classroom. The School Science Review 97, 86–92.
- Belova, N., Eilks, I., 2015. Learning with and about advertising in chemistry education with a lesson plan on natural cosmetics – a case study. Chemistry Education Research and Practice 16, 578–588. https://doi.org/10.1039/C5RP00035A
- Black, P., Wiliam, D., 1998. Assessment and Classroom Learning. Assessment in Education: Principles, Policy & Practice 5, 7–74. https://doi.org/10.1080/0969595980050102
- Black, S., 2016. Recognizing the Importance of Vaccine Confidence. EBioMedicine 12, 28–29. http://dx.doi.org/10.1016/j.ebiom.2016.08.042
- Broniatowski, D.A., Jamison, A.M., Qi, S., AlKulaib, L., Chen, T., Benton, A., Quinn, S.C., Dredze, M., 2018. Weaponized Health Communication: Twitter Bots and Russian Trolls Amplify the Vaccine Debate. Am J Public Health 108, 1378–1384. https://doi.org/10.2105/AJPH.2018.304567
- Bybee, R., 1997. Toward an understanding of scientific literacy, in: Graber, W., Bolte, C. (Eds.), Scientific Literacy. Institute for Science Education (IPN), Kiel, Germany.
- Carrillo-Santisteve, P., Lopalco, P.L., 2012. Measles still spreads in Europe: who is responsible for the failure to vaccinate? Clinical Microbiology and Infection 18, 50–56. https://doi.org/10.1111/j.1469-0691.2012.03982.x
- Carver, R.B., Wiese, E.F., Beivik, J., 2014. Frame Analysis in Science Education: A Classroom Activity for Promoting Media Literacy and Learning about Genetic Causation. International Journal of Science Education, Part B: Communication and Public Engagement 4, 211–239.
- Cedefop, 2017. Defining, writing and applying learning outcomes: a European handbook. Luxembourg: Publications Office of the European Union.
- Chevallier-Le Guyader, M.-F., 2015. Faire de la science un enjeu de culture: quels prérequis? Culture et recherche Automne-Hiver 2015-2016, 22–23.

- Chou, W.-Y.S., Oh, A., Klein, W.M.P., 2018. Addressing Health-Related Misinformation on Social Media. JAMA 320, 2417–2418. https://doi.org/10.1001/jama.2018.16865
- Ciampaglia, G.., Menczer, F., 2018. Misinformation and biases infect social media, both intentionally and accidentally [WWW Document]. The Conversation. URL https://theconversation.com/misinformation-and-biases-infect-social-media-both-intentionally-and-accidentally-97148
- Clavel, J.G., Crespo, F.J.G., Méndez, I., 2016. Are teacher characteristics and teaching practices associated with student performance? (No. Policy Brief No. 11). IEA, Amsterdam, the Netherlands.
- Cook, J., 2017. Inoculation theory: Using misinformation to fight misinformation [WWW Document]. The Conversation. URL http://theconversation.com/inoculation-theory-using-misinformation-to-fight-misinformation-77545 (accessed 1.15.19).
- Cook, J., 2015. Busting myths: a practical guide to countering science denial [WWW Document]. The Conversation. URL http://theconversation.com/busting-myths-a-practical-guide-to-countering-science-denial-42618 (accessed 2.12.19).
- Cook, J., Bedford, D., Mandia, S., 2014. Raising Climate Literacy Through Addressing Misinformation: Case Studies in Agnotology-Based Learning. Journal of Geoscience Education 62, 296–306.
- Cook, J., Lewandowsky, S., 2016. Rational Irrationality: Modeling Climate Change Belief Polarization Using Bayesian Networks. Topics in Cognitive Science 8, 160–179. https://doi.org/10.1111/tops.12186
- Cook, J., Lewandowsky, S., Ecker, U.K.H., 2017. Neutralizing misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence. PLOS ONE 12, e0175799. https://doi.org/10.1371/journal.pone.0175799
- Cook, J., Oreskes, N., Doran, P.T., Anderegg, W.R.L., Verheggen, B., Maibach, E.W., Carlton, J.S., Lewandowsky, S., Skuce, A.G., Green, S.A., Nuccitelli, D., Jacobs, P., Richardson, M., Winkler, B., Painting, R., Rice, K., 2016. Consensus on consensus: A synthesis of consensus estimates on human-caused global warming. Environmental Research Letters 11. https://doi.org/10.1088/1748-9326/11/4/048002
- Council of Europe, 2016. Competences for Democratic Culture: Living Together as Equals in Culturally Diverse Democratic Societies. Council of Europe Publishing, Strasbourg.
- Council of Europe, 2010. Council of Europe Charter on Education for Democratic Citizenship and Human Rights Education (Recommendation CM/Rec(2010)7 and explanatory memorandum No. CM/Rec(2010)7). Council of Europe Publishing, Strasbourg.
- Council of the European Union, 2018a. Council Recommendation of 22 May 2018 on Key Competences for Lifelong Learning (No. OJ 2018/C 189/01). Official Journal of the European Union.
- Council of the European Union, 2018b. Council Recommendation of 22 May 2018 on Promoting Common Values, Inclusive Education, and the European Dimension of Teaching (No. OJ 2018/C 195/01). Official Journal of the European Union.
- Council of the European Union, 2016a. Council Recommendation of 30 May 2016 on Developing Media Literacy and Critical Thinking through Education and Training. (No. OJ 2016/C 212/05). Official Journal of the European Union.

- Council of the European Union, 2016b. Council conclusions of 27 May 2016 on the transition towards an Open Science system.
- Council of the European Union, 2012. Council Recommendation of 20 December 2012 on the validation of non-formal and informal learning (No. OJ 2012/C 398/01). Official Journal of the European Union.
- CREDOC, 2013. La curiosité scientifique des français et leur désir de développer leurs connaissances. Etude réalisée en partenariat avec Universcience.
- De Coster, I., Sigalas, E., Noorani, S., McCallum, E., 2017. Citizenship Education at School in Europe – 2017 (Eurydice Brief). European Commission.
- DeBoer, G.E., 2000. Scientific Literacy: Another Look at Its Historical and Contemporary Meanings and Its Relationship to Science Education Reform. Journal of Research in Science Teaching 37, 582–601.
- Dinis da Costa, P., Araújo, L., 2018. Quality of Teaching and Learning in Science (JRC Science for Policy Report No. EUR 28865 EN). Publications Office of the European Union, Luxembourg.
- Dixson, D.D., Worrell, F.C., 2016. Formative and Summative Assessment in the Classroom. Theory Into Practice 55, 153–159. https://doi.org/10.1080/00405841.2016.1148989
- Echazarra, A., Salinas, D., Méndez, I., Denis, V., Rech, G., 2016. How teachers teach and students learn: Successful strategies for school (OECD Education Working Papers No. 130). OECD Publishing, Paris. https://doi.org/10.1787/5jm29kpt0xxx-en
- EMMI, 2012. Kerettanterv az általános iskola 5-8. évfolyamára. Fizika. (No. 51/2012. (XII. 21.) számú EMMI rendelet 2. melléklete). EMMI.
- Eshach, H., 2007. Bridging In-school and Out-of-school Learning: Formal, Non-Formal, and Informal Education. Journal of Science Education and Technology 16, 171–190. http://dx.doi.org/10.1007/s10956-006-9027-1
- European Commission, 2018a. Proposal for a Council Recommendation on Key Competences for LifeLong Learning (Commission Staff Working Document. Accompanying the document No. SWD(2018) 14 final). European Commission, Brussels.
- European Commission, 2018b. Education and Training Monitor 2018. Luxembourg: Publications Office of the European Union.
- European Commission, 2018c. Fake News and Disinformation Online (Flash Eurobarometer No. 464).
- European Commission, 2018d. Antimicrobal Resistance (Special Eurobarometer No. 478).
- European Commission, 2018e. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Building a Stronger Europe: the Role of Youth, Education and Culture Policies (No. COM(2018) 268 final).
- European Commission, 2018f. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Strengthening European Identity through Education and Culture. The European Commission's contribution to the Leaders' meeting in Gothenburg, 17 November 2017 (No. COM(2018) 22 final).

- European Commission, 2018g. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Digital Action Plan (No. COM(2018) 22 final).
- European Commission, 2018h. Proposal for a Regulation of the European Parliament and of the Council Establishing "Erasmus": the Union Programme for Education, Training, Youth and Sport and Repealing Regulation (EU) No 1288/2013 (No. COM(2018) 367 final).
- European Commission, 2018i. Study on Supporting School Innovation Across Europe. Final report. Luxembourg: Publications Office of the European Union.
- European Commission, 2017a. Climate Change (Special Eurobarometer No. 459).
- European Commission, 2017b. Attitudes of European Citizens towards the Environment (Special Eurobarometer No. 468).
- European Commission, 2017c. Attitudes towards the impact of digitisation and automation on daily life (Special Eurobarometer No. 460).
- European Commission, 2016. Open Innovation Open Science Open to the World – a vision for Europe. Luxembourg: Publications Office of the European Union.
- European Commission, 2015a. Science Education for Responsible Citizenship (No. EUR 26893 EN). European Commission.
- European Commission, 2015b. Youth work and non-formal learning in Europe's education landscape. A quarter of a century of EU cooperation for youth policy and practice. Luxembourg: Publications Office of the European Union.
- European Commission, 2011. Science Education in Europe: National Policies, Practices and Research. Eurydice, Brussels.
- European Commission, 2007. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A European approach to media literacy in the digital environment (No. COM(2007) 833 final.). European Commission.
- European Commission, 1995. Teaching and Learning. Towards the Learning Society (White Paper on Education and Training No. COM(95) 590 final). Brussles.
- European Commission/EACEA/Eurydice, 2016. Promoting Citizenship and the Common Values of Freedom, Tolerance and Non-Discrimination through Education: Overview of Education Policy Developments in Europe Following the Paris Declaration of 17 March 2015. Publications Office of the European Union, Luxembourg.
- Ferrara, E., 2017. Disinformation and social bot operations in the run up to the 2017 French presidential election. First Monday 22. https://doi.org/10.5210/fm.v22i8.8005
- Ford, C.L., Yore, L.D., 2012. Toward Convergence of Critical Thinking, Metacognition, and Reflection: Illustrations from Natural and Social Sciences, Teacher Education, and Classroom Practice, in: Zohar, A., Dori, Y.J. (Eds.), Metacognition in Science Education: Trends in Current Research, Contemporary Trends and Issues in Science Education. Springer Netherlands, Dordrecht, pp. 251–271. https://doi.org/10.1007/978-94-007-2132-6_11

- Gaumont, N., Panahi, M., Chavalarias, D., 2018. Reconstruction of the socio-semantic dynamics of political activist Twitter networks – Method and application to the 2017 French presidential election. PLOS ONE 13, e0201879. https://doi.org/10.1371/journal.pone.0201879
- Golubeva, I., 2018. The links between education and active citizenship/civic engagement (Ad hoc report No. 1/2018). NESET II.
- Grajkowski, W., Ostrowska, B., Poziomek, U., 2014. Core Curriculum for Science Subjects in Selected Countries (Study Report). Educational Research Institute, Warsaw.
- Guyon, E., Maitte, B., 2008. Le partage des savoirs scientifiques. La revue pour l'histoire du CNRS [Online]. https://doi.org/10.4000/histoire-cnrs.8322
- Halonen, J., Aksela, M., 2018. Non-formal science education: The relevance of science camps. 1 6, 64–85–64–85. https://doi.org/10.31129/LUMAT.6.2.316
- Hanss, D., Böhm, G., 2010. Can I Make a Difference? The Role of General and Domain-specific Self-Efficacy in Sustainable Consumption Decisions.
- Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J., Bonn, A., 2018. Innovation in open science, society and policy – setting the agenda for citizen science, in: Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J., Bonn, A. (Eds.), Citizen Science: Innovation in Open Science, Society and Policy. UCL Press, London, pp. 1–23.
- Helfand, D.J., 2016. A survival guide to the misinformation age: scientific habits of mind. Columbia University Press, New York.
- Higgins, S., 2014. Critical thinking for 21st-century education: A cyber-tooth curriculum? Prospects 44, 559–574. https://doi.org/10.1007/s11125-014-9323-0
- Hobbs, R., 2010. Digital and Media Literacy: A Plan of Action. A White Paper on the Digital and Media Literacy Recommendations of the Knight Commission on the Information Needs of Communities in a Democracy. Aspen Institute.
- Hodson, D., 2010. Science Education as a Call to Action. Canadian Journal of Science, Mathematics and Technology Education 10, 197–206. https://doi.org/10.1080/14926156.2010.504478
- Holbrook, J., Rannikmae, M., 2009. The Meaning of Scientific Literacy. International Journal of Environmental & Science Education 4, 275–288.
- Huet, S., 2018. Polémique sur la culture scientifique. Le Monde, Sciences2, Blog post. URL http://huet.blog.lemonde.fr/2018/02/27/polemique-sur-la-culture-scientifique/ (accessed 12.12.18).
- Jeangène Vilmer, J.-B., Escorcia, A., Guillaume, M., Herrera, J., 2018. Information Manipulation: A Challenge for Our Democracies. A report by the Policy Planning Staff (CAPS) of the Ministry for Europe and Foreign Affairs and the Institute for Strategic Research (IRSEM) of the Ministry for the Armed Forces, Paris.
- Jerrim, J., Oliver, M., Sims, S., 2019. The relationship between inquiry-based teaching and students' achievement. New evidence from a longitudinal PISA study in England. Learning and Instruction 61, 35–44. https://doi.org/10.1016/j.learninstruc.2018.12.004
- Kahan, D.M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L.L., Braman, D., Mandel, G., 2012. The polarizing impact of science literacy and numeracy on perceived climate change risks. Nature Climate Change 2, 732–735. https://doi.org/10.1038/nclimate1547

- Larson, H., de Figueiredo, A., Karafillakis, E., Rawal, M., 2018. State of Vaccine Confidence in the EU 2018. European Commission, Luxembourg: Publications Office of the European Union.
- Las Vergnas, O., 2015. CSTI et éducation populaire. Culture et recherche Automne-Hiver 2015-2016, 27–28.
- Las Vergnas, O., 2011. L'institutionnalisation de la «culture scientifique et technique», un fait social français (1970 – 2010). Savoirs 3, 9–60.
- Laugksch, R.C., 2000. Scientific literacy: A conceptual overview. Science Education 84, 71–94. https://doi.org/10.1002/(SICI)1098-237X(200001)84:1<71::AID-SCE6>3.0.CO;2-C
- Lazer, D.M.J., Baum, M.A., Benkler, Y., Berinsky, A.J., Greenhill, K.M., Menczer, F., Metzger, M.J., Nyhan, B., Pennycook, G., Rothschild, D., Schudson, M., Sloman, S.A., Sunstein, C.R., Thorson, E.A., Watts, D.J., Zittrain, J.L., 2018. The science of fake news. Science 359, 1094–1096. https://doi.org/10.1126/science.aao2998
- Leviston, Z., Walker, I., Morwinski, S., 2013. Your opinion on climate change might not be as common as you think. Nature Climate Change 3, 334–337. https://doi.org/10.1038/nclimate1743
- Lewandowsky, S., Oberauer, K., 2016. Motivated Rejection of Science. Current Directions in Psychological Science 25, 217–222. https://doi.org/10.1177/0963721416654436
- Lindner, M., Kubat, C., 2014. Science Camps in Europe–Collaboration with Companies and School, Implications and Results on Scientific Literacy. Science Education International 25, 79–85.
- Liu, X., 2013. Expanding Notions of Scientific Literacy: A Reconceptualization of Aims of Science Education in the Knowledge Society, in: Mansour, N., Wegerif, R. (Eds.), Science Education for Diversity: Theory and Practice. Springer Netherlands, Dordrecht, pp. 23–39. https://doi.org/10.1007/978-94-007-4563-6_2
- Marian, H., Jackson, C., 2017. Inquiry-based learning: a framework for assessing science in the early years. Early Child Development and Care 187, 221–232. https://doi.org/10.1080/03004430.2016.1237563
- Marks, R., Otten, J., Eilks, I., 2010. Writing news spots about science: a way to promote scientific literacy. The School Science Review 92, 55–64.
- Marleau, J.N., Girling, K.D., 2017. Keeping science's seat at the decision-making table: Mechanisms to motivate policy-makers to keep using scientific information in the age of disinformation. FACETS 2, 1045–1064. https://doi.org/10.1139/facets-2017-0087
- Marty, L., Venturini, P., Almqvist, J., 2017. Teaching traditions in science education in Switzerland, Sweden and France: A comparative analysis of three curricula. European Educational Research Journal Contribution to a special issue, 1–20.
- Mayer, R.E., 2004. Should There Be a Three-Strikes Rule Against Pure Discovery Learning? American Psychologist 59, 14–19. https://doi.org/10.1037/0003-066X.59.1.14
- McCright, A.M., Charters, M., Dentzman, K., Dietz, T., 2016. Examining the Effectiveness of Climate Change Frames in the Face of a Climate Change Denial Counter-Frame. Topics in Cognitive Science 76–97. https://doi.org/10.1111/tops.12171
- McCurdy, R.C., 1958. Toward a Population Literate in Science. The Science Teacher 25, 366–408.

- McDougall, J., Livingstone, S., Sefton-Green, J., 2014. 'Media and Information Education' in the UK: Report for Cost/ANR.
- McDougall, J., Readman, M., Wilkinson, P., 2018a. The Uses of (Digital) Literacy. Learning, Media and Technology. https://doi.org/10.1080/17439884.2018.1462206.
- McDougall, J., Zezulkova, M., van Driel, B., Sternadel, D., 2018b. Teaching media literacy in Europe: evidence of effective school practices in primary and secondary education (NESET II report). Luxembourg: Publications Office of the European Union.
- Mostafa, T., Echazarra, A., Guillou, H., 2018. The science of teaching science: An exploration of science teaching practices in PISA 2015 (OECD Education Working Paper No. No. 188). OECD Publishing, Paris.
- Nemzeti Alaptanterv, 2012. . Magyar Közlöny 10639– 847.
- Nikolov, D., Oliveira, D.F.M., Flammini, A., Menczer, F., 2015. Measuring online social bubbles. PeerJ Computer Science 1, e38. https://doi.org/10.7717/peerj-cs.38
- Norqvist, L., Leffler, E., 2017. Learning in non-formal education: Is it “youthful” for youth in action? Int Rev Educ 63, 235–256. https://doi.org/10.1007/s11159-017-9631-8
- Norris, S.P., Phillips, L.M., 2003. How literacy in its fundamental sense is central to scientific literacy. Science Education 87, 224–240. https://doi.org/10.1002/sce.10066
- Nyst, C., Monaco, N., 2018. State-Sponsored Trolling. How Governments Are Deploying Disinformation as Part of Broader Harassment Campaigns. Institute for the Future, Palo Alto.
- OECD, 2018a. Preparing our youth for an inclusive and sustainable world. The OECD PISA global competence framework. OECD.
- OECD, 2018b. How do science teachers teach science — and does it matter? (PISA in Focus No. 90). OECD.
- OECD, 2017. PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematic, Financial Literacy and Collaborative Problem Solving, revised edition. PISA, OECD Publishing, Paris.
- OECD, 2016a. PISA 2015 Results (Volume I): Excellence and Equity in Education. PISA, OECD Publishing, Paris.
- OECD, 2016b. PISA 2015 Results (Volume II): Policies and Practices for Successful Schools. PISA, OECD Publishing, Paris.
- Poortinga, W., Fisher, S., Böhm, G., Steg, L., Whitmarsh, L., Ogunbode, C., 2018. European Attitudes to Climate Change and Energy: Topline Results from Round 8 of the European Social Survey (No. 9), ESS Topline Results Series. European Spcial Survey ERIC.
- Ranney, M.A., Clark, D., 2016. Climate Change Conceptual Change: Scientific Information Can Transform Attitudes. Topics in Cognitive Science 8, 49–75. https://doi.org/10.1111/tops.12187
- Reeve, J., 1989. The interest-enjoyment distinction in intrinsic motivation. Motivation and Emotion. 13(2), 83-103. https://doi.org/10.1007/BF00992956
- Roberts, D.A., 2007. Scientific Literacy/Science Literacy, in: Abell, S.K., Appleton, K., Hanuscin, D.L. (Eds.), Handbook of Research on Science Education. Routledge, New York. https://doi.org/10.4324/9780203824696-32

- Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., Hemmo, V., 2007. Science Education Now: A Renewed Pedagogy for the Future of Europe. European Commission, Brussels.
- Roozenbeek, J., van der Linden, S., 2018. The fake news game: actively inoculating against the risk of misinformation. Journal of Risk Research 1–11. https://doi.org/10.1080/13669877.2018.1443491
- Sadler, T.D., Zeidler, D.L., 2009. Scientific Literacy, PISA, and Socioscientific Discourse: Assessment for Progressive Aims of Science Education. Journal of Research in Science Teaching 46, 909–921.
- Santos, W.L.P., 2009. Scientific literacy: A Freirean perspective as a radical view of humanistic science education. Science Education 93, 361–382.
- Schukajlow, S., Krug, A., 2014. Are interest and enjoyment important for students' performance? In Nicol, C., Oesterle, S., Liljedahl, P., & Allan, D. (Eds.) Proceedings of the Joint Meeting of PME 38 and PME-NA 36, Vol. 5, pp. 129-136. Vancouver, Canada: PME.
- SciLit, 2016. Scientific literacy at the school: a proposal of a new methodology. Scientific literacy at the school: improving strategies and building new practices of science teaching in early years education (SciLit) (No. 2016-1-ES01-KA201- 025282). Co-funded by the Erasmus+ programme of the European Union.
- Shen, B.S.P., 1975. Science Literacy and the Public Understanding of Science, in: Day, S.B. (Ed.), Communication of Scientific Information. Krager, Basel, pp. 44–52.
- Silva, E., 2009. Measuring skills for 21st-century learning. The Phi Delta Kappan 90, 630–634.
- 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. Learning, Teaching and Assessment, Innovation in Science Education and Technology. Springer, pp. 65–88.
- Stockard, J., Wood, T.W., Coughlin, C., Rasplica Khoury, C., 2018. The Effectiveness of Direct Instruction Curricula: A Meta-Analysis of a Half Century of Research. Review of Educational Research 88, 479–507. https://doi.org/10.3102/0034654317751919
- Stone, M., 2014. Scientix the Community for Science Education in Europe. European Schoolnet, Brussels.
- 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, 1–34. https://doi.org/10.1080/03057267.2013.802463
- Tournay, V., 2018. La culture scientifique est à reconquérir [WWW Document]. HuffingtonPost.fr. URL https://www.huffingtonpost.fr/virginie-tournay/ne-nous-reposons-pas-sur-nos-lauriers-en-france-la-culture-scientifique-est-a-reconquerir_a_23369215/ (accessed 12.12.18).
- UNESCO, 1993. Final Report: International forum on scientific and technological literacy for all. United Nations Educational, Scientific and Cultural Organisation, Paris.
- United Nations, 2017. The Sustainable Development Goals Report 2017. United Nations, New York.
- van der Linden, S., Leiserowitz, A., Rosenthal, S., Maibach, E., 2017. Inoculating the Public against Misinformation about Climate Change. Global Challenges 1. https://doi.org/10.1002/gch2.201600008

- Varol, O., Ferrara, E., Davis, C.A., Menczer, F., Flammini, A., 2017. Online Human-Bot Interactions: Detection, Estimation, and Characterization. Presented at the International AAAI Conference on Web and Social Media, p. 10.
- Vieira, R.M., Tenreiro-Vieira, C., 2016. Fostering Scientific Literacy and Critical Thinking in Elementary Science Education. International Journal of Science and Mathematics Education 14, 659–680. https://doi.org/10.1007/s10763-014-9605-2
- Vosoughi, S., Roy, D., Aral, S., 2018. The spread of true and false news online. Science 359, 1146–1151. https://doi.org/10.1126/science.aap9559
- Weiss, R., 2017. Nip misinformation in the bud. Science 358, 427–427. https://doi.org/10.1126/science.aar2683
- Wickman, P.O., Liberg, C., Östman, L., 2012. Transcending science: Scientific literacy and Bildung for the 21st century, in: Jorde, D., Dillon, J. (Eds.), Science Education Research and Practice in Europe. Sense, Rotterdam, pp. 39–61.
- World Health Organization, 2016. Immunization highlights 2015. Report of the WHO Regional Office for Europe. Copenhagen, Denmark.
- Yacoubian, H.A., 2017. Scientific literacy for democratic decision-making. International Journal of Science Education 1–20. https://doi.org/10.1080/09500693.2017.1420266
- Yore, L., 2012. Science Literacy for All: More than a Slogan, Logo, or Rally Flag!, in: Tan, K.C.D., Kim, M. (Eds.), Issues and Challenges in Science Education Research Moving Forward. Springer, Dordrecht, Heidelberg, New York, London, pp. 5–23. https://doi.org/10.1007/978-94-007-3980-2_2
- Yore, L.D., Pimm, D., Tuan, H.-L., 2007. The Literacy Component of Mathematical and Scientific Literacy. Int J of Sci and Math Educ 5, 559–589. https://doi.org/10.1007/s10763-007-9089-4
- Zhang, L., 2016. Is Inquiry-Based Science Teaching Worth the Effort?: Some Thoughts Worth Considering. Science & Education 25, 897–915. https://doi.org/10.1007/s11191-016-9856-0

European societies are faced with emerging threats relating to the spread of disinformation and pseudo-science. In this context, fostering scientific literacy can provide people with tools to navigate and critically address the vast amounts of information exchanged in public debate, and support democratic processes. Building on a review of academic and policy literature, this study aims to enable Members of the European Parliament to form their opinions on the state of scientific literacy in the EU and on potential education policy responses to better prepare scientifically literate citizens.

PE 629.188

IP/B/CULT/IC/2018-129

Print ISBN 978-92-846-4679-1 | doi:10.2861/806854 | QA-02-19-202-EN-C
PDF ISBN 978-92-846-4675-3 | doi:10.2861/2088 | QA-02-19-202-EN-N