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ALLEA STATEMENT ON EARLY LEARNING OPPORTUNITIES FOR SHAPING A SCIENTIFICALLY LITERATE SOCIETY

Executive summary

It is apparent that, now more than ever, society's well-being, progress, and survival will require 'scientifically literate' citizens, as science and technology become increasingly interwoven with our daily lives. While this interrelationship may not always be front of mind, the centrality of technology in the modern world becomes particularly evident during crises. Furthermore, new technologies and scientific progress always bring up ethical questions (currently, this is exemplified by generative Artificial Intelligence (AI), genome editing, and vaccination), and it will become even more crucial for upcoming generations to learn how to recognise and navigate these ethical considerations.

This ALLEA Statement argues that primary and post-primary science education play a key role in supporting all young learners in gaining insight into how the natural sciences are integral to our everyday lives, thereby contributing to their development into informed and active citizens. It advocates for strengthening the role of science education curricula in improving societal understanding of the Nature of Science (NOS) and encouraging learning on how to identify, comprehend, and navigate related ethical dilemmas among the wider public, which will enable the creation of a scientifically literate society. Key recommendations include incorporating learning outcomes related to the NOS and research ethics into primary and post-primary science curricula, the integration of NOS and research ethics pedagogies into existing curricula and in initial teacher education (ITE) and continuous professional learning (CPL) programmes for teachers, among others.

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Introduction

It is apparent that, now more than ever, society's well-being, progress, and survival will require 'scientifically literate' (see Box 1) citizens, as science and technology become increasingly interwoven with our daily lives. Most of us rely on readily available knowledge and the smooth functioning of technology without ever needing to comprehend the depth of complexity that underpins them. But there are times when the significance of science becomes particularly evident, for example, during the Covid-19 pandemic, the energy crisis, or when considering the impacts of climate change and biodiversity loss. In addition, scientific progress has always challenged ethical norms (in present days, this is exemplified by generative Artificial Intelligence (AI), genome editing, and vaccination), and it will become even more crucial for upcoming generations to learn how to recognise and navigate these ethical considerations.

Science education, either as a separate discipline or as part of integrated STEM (Science, Technology, Engineering, and Mathematics) education approaches,[1] is embedded in virtually all current primary and post-primary education curricula worldwide. For some students, engagement with these curricula lays the groundwork for future studies or careers in STEM related fields. Throughout higher education and professional careers, continual engagement with research ethics and integrity programmes has the potential to support them in becoming reliable, honest, respectful, and accountable researchers.[2] However, it is apparent that a majority of students worldwide do not pursue science education beyond second level.[3] Primary and post-primary science education therefore have key roles in supporting all young learners in developing an understanding of how the natural sciences are integral to our everyday life and surroundings, an understanding that is key for informed and active citizenship.

This ALLEA Statement advocates for strengthening the role of science education curricula in improving societal understanding of the Nature of Science (NOS)[4] and encouraging learning on how to identify, comprehend, and navigate related ethical dilemmas among the wider public. It argues that these actions are imperative for equipping young learners with the requisite knowledge, skills, and values to become informed, critical, responsible, and ethically conscious participants in a scientifically literate society.

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1 We acknowledge that 'science' is frequently interpreted in a broader sense, often including the social sciences and humanities. However, as science education is generally understood to exclusively cover the natural sciences, this statement will accordingly use 'science' to refer to astronomy, physics, chemistry, earth sciences, and biology. For the purposes of this statement, 'science education' will be referred to for simplicity, although the same principles apply to integrated STEM education approaches.

2 For example, see ALLEA Statement on "Ethics Education in Science" (2013) and ALLEA "European Code of Conduct for Research Integrity – 2023 Revised Edition" (2023).

3 Global Education Monitoring Report Team. (2023). UNESCO "SDG 4 mid-term progress review: progress since 2015 has been far too slow". Available from: https://unesdoc.unesco.org/ark:/48223/pf0000386852.

4 The term 'Nature of Science' relates to the epistemological and sociological underpinnings of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge. Lederman, N. G. (1992). "Students' and teachers' conceptions of the nature of science: A review of the research," *Journal of Research in Science Teaching*, 29/4: 331–59. DOI: 10.1002/tea.3660290404

Box 1: Defining scientific literacy

There are many interpretations of what 'scientific literacy' comprises. Some consider scientific knowledge or societal usefulness central to scientific literacy, while others advocate for global citizenship and socio-ecojustice.[5] Roberts (2007) puts forward two visions of scientific literacy: the first vision focuses on decontextualised science subject knowledge and preparation for careers in science; and the second relates to the ability to make sense of science, to connect science to everyday perspectives, and to make decisions regarding everyday socio-scientific and environmental issues.[6,7] A third vision of scientific literacy that has recently been proposed moves towards a more politicised vision of science education aimed at dialogic emancipation, critical global citizenship, and socio-ecojustice where controversial current issues are central to curricula.[8] Other research highlights an understanding of the NOS as an essential component of scientific literacy.[9,10] More recently, and drawing on all the aspects of scientific literacy referred to above, PISA defines scientific literacy as 'the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen'.[11]

Scientific literacy and the Nature of Science education

Globally, science education reform policy has advocated for scientific literacy, encompassing the development of disciplinary content knowledge (including knowledge about the NOS), skills, attitudes, and values, as well as the ability to apply this learning to make sense of the socio-scientific and environmental issues that citizens will encounter.[12] This focus on strengthening scientific literacy, which includes the development of students' knowledge about the NOS, is important. Research has shown that the inclusion of NOS content and pedagogies in curricula offers benefits for both teaching and learning.

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5 Broderick, N. (2023). "Exploring different visions of scientific literacy in Irish primary science education: core issues and future directions," *Irish Educational Studies*, 1–21. DOI: 10.1080/03323315.2023.2230191

6 Roberts, D. A. (2007). "Scientific literacy/Science literacy." In *Handbook of research on science education*, edited by S. K. Abell and N. G. Lederman, 729–780. Lawrence Erlbaum Associates. Mahwah, NJ.

7 Haglund, J., & Hultén, M. (2017). "Tension between visions of science education," *Science & Education*, 26/3–4: 323–44. DOI: 10.1007/s11191-017-9895-1

8 Sjöström, J., and Eilks, I. (2018). "Reconsidering different visions of scientific literacy and science education based on the concept of Bildung." In *Cognition, Metacognition, And Culture In STEM Education: Learning, Teaching And Assessment*, edited by Y. J. Dori, Z. R. Mevarech, and D. R. Baker, 65–88. Springer International Publishing.

9 McComas, W. F., Clough, M. P., & Nouri, N. (2020). "Nature of Science and Classroom Practice: A Review of the Literature with Implications for Effective NOS Instruction." *Science: Philosophy, history and education*, pp. 67–111. DOI: 10.1007/978-3-030-57239-6_4

10 Murphy, C., Smith, G., & Broderick, N. (2019). "A Starting Point: Provide Children Opportunities to Engage with Scientific Inquiry and Nature of Science," *Research in Science Education*, 51/6: 1759–93. DOI: 10.1007/s11165-019-9825-0

11 PISA. (2023). "2022 Results (Volume I) The State of Learning and Equity in Education". Available from: https://www.oecd-ilibrary.org/education/pisa-2022-results-volume-i_53f23881-en.

12 Murphy, C., Venkat, H., Broderick, N., Kelly, O., Leahy, M., Butler, D., Harbison, L., Lawlor, C., & Naughton, Y. (2023). "STEM Education: Curriculum & literature overview & Primary science education: systematic literature review." Dublin: National Council for Curriculum and Assessment.

For example, from a teaching perspective, it is apparent that when teachers adopt NOS pedagogies, they become more confident in using inquiry-based methodologies, afford their students more opportunities to plan and carry out their own investigations, and create more opportunities for discussion, collaboration, and reflection in science class.[13, 14,15] From a learning perspective, engagement with NOS pedagogies results in students developing a greater awareness of scientific processes, greater critical thinking and problem-solving skills, and the improved ability to make links between science in school and science in the real world. This would be beneficial, regardless of whether they pursue higher education in STEM, social sciences, humanities, or no further education at all.

It is evident from the research literature that learning about the NOS has numerous benefits for teaching and learning science. We further contend that providing students with opportunities to learn about the NOS during school is important, and is to be welcomed, as it also has the potential to make important contributions to:

- **Upholding trust in science, scientists, and scientific institutions:** Uncertainty and different interpretations are imperative to science. Moreover, science has the ability to correct itself; the availability of new data and insights continuously lead to the (rightful) rejection or fine-tuning of hypotheses and the incremental evolution of knowledge. We have to acknowledge that while the path to new knowledge can sometimes be bumpy in and of itself, in combination with limited public understanding of the NOS and scientific processes, this can easily spiral into the erosion of trust in science, scientists, and their institutions. Trust is an essential component of democracy. Without it, citizens cannot engage meaningfully in the democratic process, and governments and regulatory bodies lack moral authority. Policy decisions in democracies are often driven by the advice of experts, and therefore trust in these experts is necessary for new policies to bear fruit. This becomes particularly relevant in times of crisis when policymaking relies heavily on science-based advice. Societal distrust can prevent effective implementation of measures intended to mitigate a crisis and bring society back on track. An early and widespread engagement with NOS pedagogies during primary and post-primary schooling would support students in developing their understanding that doubt, debate, and uncertainty are fundamental to knowledge creation, and would play an important role in increasing public understanding of the challenges that are inherent to managing a crisis.

- **Filtering accurate information from legitimate sources:** The rise of social media has dramatically transformed how we share information, knowledge, and ideas. Where before we used to refer to our newspaper of choice as a trusted source of information, virtually any view or idea can now be broadly shared by anyone at any time without evidence or editorial oversight. This creates huge opportunities for bringing science into society, but at the same time, it challenges us to become more critical judges of which information and sources to trust.

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13 Khishfe, R. (2022). "Improving Students' Conceptions of Nature of Science: A Review of the Literature," *Science & Education*, 32/6: 1887–931. DOI: 10.1007/s11191-022-00390-8

14 McComas, W. F., Clough, M. P., & Nouri, N. (2020). "Nature of Science and Classroom Practice: A Review of the Literature with Implications for Effective NOS Instruction." *Science: Philosophy, history and education,* pp. 67–111. DOI: 10.1007/978-3-030-57239-6_4

15 Murphy, C., Venkat, H., Broderick, N., Kelly, O., Leahy, M., Butler, D., Harbison, L., Lawlor, C., & Naughton, Y. (2023). "STEM Education: Curriculum & literature overview & Primary science education: systematic literature review." Dublin: National Council for Curriculum and Assessment.

The rise of content produced by AI and our self-sorting on social media through filter bubbles and echo chambers adds more dimensions to this challenge. A better understanding of the NOS (in terms of, for example, who can be considered an expert and who cannot, why scientists sometimes disagree, what their motivations are, and how independent they are) will not only support the next generation in accurately recognising reliable information and trustable sources, but will also help us understand how science can be used and abused, thereby making society less susceptible to science mis- and dis-information.[16]

- **Understanding the relationship between science and policy:** Policymakers sometimes need to make far-reaching decisions based on incomplete and continuously changing scientific knowledge, while at the same time taking economic, ideological, cultural, and ethical factors into consideration. In times of crisis, and in polarised political landscapes, science risks becoming politicised; for example, when politicians try to discredit scientists who present findings that contradict their political or ideological agendas, or when they selectively cite (spurious) scientific studies that support their ideas, while disregarding others. In such circumstances, the independence and integrity of scientists often end up being questioned, thereby risking the further erosion of public trust. A clearer public understanding of the different roles and responsibilities of scientists and policymakers, together with stronger scientific literacy, would support young people in developing the necessary tools and skills to enable them to more effectively identify when such politicisation is happening.

Scientific literacy and ethics education

The evaluation of science education achievements as part of the European Commission's Horizon Europe 2020 Science with and for Society (SwafS) programme states: "*We need science education for all, gender equality in our organisations, ethics and integrity embedded in research, communication we can trust, Open Science, and ultimately place citizens at the core to ensure excellent Research and Innovation to tackle the challenges of today for a better future.*"[17] We advocate that central to these objectives is a society that is sufficiently scientifically literate, and anticipate that strengthening the role of research ethics in science education curricula could directly contribute to Europe's Digital Education Action Plan,[18] its Action Plan against Disinformation,[19] and broader aims to foster literacy in the next generation.[20]

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16 See ALLEA Discussion Paper "Fact or Fake? Tackling Science Disinformation" (2021).

17 European Commission – DG for Research and Innovation. (2020). "Science Education – Achievements in Horizon 2020 and recommendations on the way forward". Available from: https://op.europa.eu/en/publication-detail/-/publication/1161168a-cbc6-11ea-adf7-01aa75ed71a1.

18 See the "EU Digital Education Action Plan 2021-2027". See also the "ALLEA Statement in Response to the European Commission's Call for Evidence on Digital Education and Digital Skills" (2022).

19 See the "EU Action Plan against Disinformation" (2018).

20 See the European Council Recommendations on "Key Competences for Lifelong Learning" (2018) and on "Pathways to School Success" (2022).

In some European countries, developing individuals' ethical values and societal moral norms is deeply interwoven with religion and is taught in schools as part of compulsory religious education curricula. In others, children often learn the principles of morality, ethics, and values without a specific context, for example through ethics, philosophy, civics, or worldview classes. In either case, learning to reflect on values and ethics at an early age contributes to moral character development and helps guide children in their behaviour throughout their lives.

It empowers children to make ethically informed decisions by equipping them with a robust framework for assessing the ethical dimensions of various situations, thereby enabling them to act responsibly, compassionately, and ethically.

In addition to such general ethics classes, stronger incorporation of *research ethics* as part of science education curricula will be needed if children are to be supported in developing the knowledge, skills, and values required to competently analyse and critically question the moral and ethical dimensions of scientific discoveries, new technologies, and experiments.

Recommendations

Include learning outcomes related to the NOS and ethics in science curricula

Many science curricula worldwide already include learning outcomes related to the NOS, whereby students are afforded opportunities to learn about how scientific knowledge is generated through activities such as gathering evidence, observing patterns, testing hypotheses, constructing models, and debating results. Students are guided towards appreciating how scientific knowledge is tentative, based on evidence, shaped by values and assumptions, involving human inference and creativity, and entwined with society.[21] However, fewer science curricula tend to include learning outcomes related to ethics in science.

Science education curricula can potentially offer many possibilities to demonstrate proper use (as well as examples of incorrect use or even misuse) of the scientific process. Introducing concepts critical to the effective and ethical application of the scientific process in an age-appropriate manner could lay the foundation for understanding responsible research conduct. We suggest that all primary and post-primary curricula should therefore include learning outcomes related to the NOS and research ethics. However, cognisant of further expansion of content in already extensive primary and secondary school curricula, we argue for effective and targeted integration of research ethics and NOS pedagogies in existing science education curricula.

Develop educational resources

Further development of modules, materials, and toolkits, as well as their exchange and availability via Open Educational Resources will greatly facilitate the integration of NOS and research ethics pedagogies into existing curricula. Moreover, increasing the enrolment of schools into participatory research and citizen-science projects would lead

21 McComas, W. F., Clough, M. P., & Nouri, N. (2020). "Nature of Science and Classroom Practice: A Review of the Literature with Implications for Effective NOS Instruction." *Science: Philosophy, history and education*, pp. 67–111. DOI: 10.1007/978-3-030-57239-6_4

to the increased exposure of young learners to science and scientists. This could contribute not only to an increased general understanding of the NOS, but may also serve to encourage the pursuit of science and technology careers by these young learners.

Provide professional learning for teachers

Professional learning programmes play a central role in ensuring that teachers continue to develop the knowledge and skill-sets required to effectively support students' learning in science.

Teaching about the NOS and research ethics requires different competences and skill-sets from those required for teaching more typical science curricula. Instead of searching for the 'truth' or a 'right answer', students need to learn that they do not necessarily need to come to a conclusion when discussing ethical perspectives – rather they need to be provided with opportunities and guidance on how to reflect on their values, and learn to provide reasoned arguments for their views and ideas. Initial teacher education (ITE) and continuous professional learning (CPL) programmes for teachers therefore need to be designed and implemented to ensure that they develop the requisite technological and pedagogical content knowledge (TPACK)[22] to effectively support their students in learning about the NOS and to engage in ethical role-modelling. Such programmes should afford teachers with opportunities to engage with the pedagogies that they will eventually implement in their teaching. We therefore advocate for national education systems to increase the resources and opportunities available for ongoing professional learning so that teachers can continue to stay informed about new developments in science and research ethics. Workshops, conferences, and networking opportunities could further provide teachers with a collaborative learning environment to share best practices and experiences.

Develop structured opportunities for exchange

It is important to note that new educational policies, curricula, and resources do not automatically reach teachers, for example, due to the lack of effective communication channels, limited professional learning opportunities, overwhelming workloads, and a general disconnect between policymakers and teachers. Therefore, it will be essential to invest in more structured opportunities for exchange between teachers, researchers, and policymakers. In addition, teachers should be provided with the opportunities and, more importantly, the time to actively contribute to the development of future science education curricula.

22 Koehler, M. J., Mishra, P., & Cain, W. (2013). "What is Technological Pedagogical Content Knowledge (TPACK)?", *Journal of Education*, 193/3: 13–9. DOI: 10.1177/002205741319300303

Recommended actions

- *Include learning outcomes related to the NOS and research ethics in primary and post-primary science curricula.*
- *Integrate NOS and research ethics pedagogies into national science/STEM education curricula more robustly, and firmly embed of these pedagogies into European education policy frameworks.*
- *Invest more substantively in the development and exchange of relevant modules, materials, and toolkits on NOS and research ethics pedagogies to complement inquiry-based teaching and learning.*
- *Increase the exposure of young learners to science (and scientists) that is relevant to their everyday lives and immediate environments, and create opportunities to reflect on these interactions.*
- *Support the development and implementation of NOS and research ethics pedagogical courses in initial teacher education (ITE) and continuous professional learning (CPL) programmes for teachers.*

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ALLEA is the European Federation of Academies of Sciences and Humanities, representing more than 50 academies from about 40 countries in Europe. Since its foundation in 1994, ALLEA speaks out on behalf of its members on European and international stages, promotes science as a global public good, and facilitates scientific collaboration across borders and disciplines. Learn more here: www.allea.org

About this statement

This ALLEA Statement has been prepared by the ALLEA Working Group Science Education, with Dr Cliona Murphy (WG chair), Mathijs Vleugel and Maria Ronald (ALLEA Secretariat) as principal authors. Additional insights were obtained from the ALLEA Permanent Working Group on Science and Ethics and external expert Dr Eve Poole. Through its Working and Expert Groups, ALLEA provides input on behalf of European academies to pressing societal, scientific, and science-policy debates and their underlying legislations. With its work, ALLEA seeks to ensure that science and research in Europe can excel and serve the interests of society.

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