frontiers | Frontiers in Communication

TYPE Perspective
PUBLISHED 03 June 2024
DOI 10.3389/fcomm.2024.1297246

OPEN ACCESS

EDITED BY
Tarla Rai Peterson,
The University of Utah, United States

REVIEWED BY
Julia Coombs Fine,
George Mason University, United States

*CORRESPONDENCE
Renato Matos Lopes
renatoml@ioc.fiocruz.br
Rachel Ann Hauser-Davis
rachel.davis@ioc.fiocruz.br

RECEIVED 19 September 2023
ACCEPTED 10 April 2024
PUBLISHED 03 June 2024

CITATION
Lopes RM, Comarú MW, Pierini MF, de Souza RA and Hauser-Davis RA (2024) Scientific communication and scientific literacy for the public perception of the importance of environmental quality for public health.
Front. Commun. 9:1297246.
doi: 10.3389/fcomm.2024.1297246

Scientific communication and scientific literacy for the public perception of the importance of environmental quality for public health

Renato Matos Lopes[1]*, Michele Waltz Comarú[1,2], Max Fonseca Pierini[1], Raphael Argento de Souza[2] and Rachel Ann Hauser-Davis[3]*

[1]Laboratório de Comunicação Celular, Instituto Oswaldo Cruz (IOC), Fundação Oswaldo Cruz, Rio de Janeiro, Brazil, [2]Instituto Federal do Rio de Janeiro, Rio de Janeiro, Brazil, [3]Laboratório de Avaliação e Promoção da Saúde Ambiental, Instituto Oswaldo Cruz (IOC), Fundação Oswaldo Cruz, Rio de Janeiro, Brazil

The association between environmental degradation, social disparities, and disease emergence has become clearer than ever in the last decades, emphasizing the need for scientific approaches to protect human and environmental health. Despite scientific consensus, however, the general public often lacks awareness and understanding of these relationships. Misinformation and compartmentalized knowledge further complicate conveying the importance of the subject to the lay population. Thus, scientists must engage in effective scientific communication and promote scientific literacy (SL) among the public. This study discusses the strategies that may be employed to overcome disinformation and enhance scientific literacy and communication, all of which are paramount to deepen the understanding of the connections between biodiversity conservation, environmental health, and public well-being, empowering individuals to take informed actions for a sustainable and healthy future.

KEYWORDS

science communication, scientific literacy, public understanding of science, environmental health, climate change, biodiversity, public health

Introduction

The recent COVID-19 syndemic has clearly highlighted that environmental quality deterioration, as well as social and economic disparities, originate diseases and exacerbate adverse human effects, requiring clear scientific approaches to protect and promote human and environmental health (Horton, 2020). Besides triggering infectious disease outbreaks, biodiversity losses directly destabilize ecosystems and negatively alter the development of progress, nutrition, security and protection against natural disasters, confirming that ecosystem degradation and health problems share common threats (Romanelli et al., 2015).

Anthropogenic activities produce and have already caused several negative impacts on environmental quality. These include, but are not limited to, decades-long global animal population declines and extinctions (Perez-Mendez et al., 2016) and climate change that threaten life in many dimensions, such as prolonged droughts that affect food production and water supplies, heat-related deaths, labor capacity loss and, as mentioned previously, changes in the epidemiology of diseases (Lancet, 2024). Thus "Anthropocene defaunation" is both a component of the planet's sixth mass extinction and an important driver of global environmental change, which is already cascading into global ecosystem functioning and human well-being (Dirzo et al., 2014; Ceballos et al., 2015). In another disastrous example, the Amazon Rainforest, one of humanity's most precious natural heritage and the largest natural reserve on the planet, reached about 45,600 km^2 deforestation rates between 2019 and 2022 in the Brazilian territory alone, according to the Brazilian National Institute for Space Research (INPE-Brazil: https://terrabrasilis.dpi.inpe.br/en) with total Amazon forest area losses in January and February 2023 of 523 km^2, the equivalent of almost 900 soccer fields a day (Imazon, 2023).

Several Sustainable Development Goals of the 2030 Agenda of the United Nations are valuable in this regard, directly linked to climate action, biodiversity and ecosystems, clean water and sanitation, sustainable cities and communities, underwater life, industry, innovation and infrastructure and quality education (UN, 2015; Bhore, 2016). This agenda is a plan of action for people, planet and prosperity. It involves different aspects, including the use of science as an important element in combating social inequality, socioeconomic development and improving health conditions and education, including awareness-raising and human and institutional capacity on mitigating environmental impacts, such as those caused by climate change (UN, 2015; Harker-Schuch et al., 2021). In this scenario, the summer of 2022 was the hottest season on record in Europe, characterized by an intense series of heat waves, which led to extremes in terms of temperature, drought and fire activity, with an estimated 61,672 heat-related deaths on the continent between May and September 2022 (Ballester et al., 2023).

Nonetheless, the importance of science is not always directly translatable to the lay public. For instance, the fact that biodiversity loss directly affects humans and public health through many different processes is a known data for most of the academic community, but this information is not necessarily clearly presented and understood to the general population. The data that reaches the population through different information channels, both formal and non-formal, is, in fact, many times false, with no clear links on how human activities negatively affect biodiversity and environmental quality. A portion of the received information is also perceived as misinformation, due to certain characteristics such as exaggerated visual aspects and incorrect spelling, although the public is simply not trained (or simply does not have enough time) to check the sources or the veracity of the received scientific content simplified to reach the lay public.

The intersection between scientific research and its public perception

Scientific disinformation is directly associated to a web of interconnected factors, encompassing political ideologies, masculinity, religion and gender, among others, contributing to the complexity of public perceptions and responses (Harsin, 2020; Edenborg, 2022; Gupta et al., 2023). Concerning political views, in particular, studies on data obtained from culturally diverse samples have demonstrated that both conservative and collectivist individuals tend to exhibit increasing false news believability (Gupta et al., 2023). Furthermore, it is important to note that low rates of scientific literacy, involving knowledge about scientific theories, trust in science and the development of critical thinking, may be strongly related to the dissemination of numerous unfounded beliefs, such as pseudoscience and conspiracy theories (Fasce and Pico, 2019; Sunyík and Cavojová, 2023). It is not uncommon for many individuals to wonder about the veracity and importance of science in general. Many people, for example, ponder the significance of studying pollution, the Greenhouse Effect, defaunation, deforestation, and the effects of toxic substances on the environment. What do all these very different issues all have to do with Public Health? Why not study just diseases and their cures, for example? Many people, in fact, consider several important scientific studies to be frivolous, questioning the relevance of studying basic issues such whale migration behavior, dolphin chemical contamination, or the reactions of worms to pesticides in the soil. Why do these studies deserve attention and funding, especially when resources could be applied elsewhere? Conservation is, thus, frequently perceived as an external imposition on local communities by outsiders, and not as a collective societal endeavor (Chan et al., 2016).

These questions highlight an intricate correlation between trust and the public perception of the importance of scientific research and a narrow focus solely prioritizing instrumental or intrinsic nature values, mainly in an economic context (Chan et al., 2016). In some cases, this may lead to interesting conservation efforts, where conservation is understood by society as an economic advantage. For example, one study verified that changes in fishing regulations, such as allowing anglers to catch more salmon, would affect the number of times people visited a certain river in the United States for recreational salmon fishing, and be likely to enhance the economic benefits derived from recreational fishing in the region (Layman et al., 1996). However, in most cases, this type of strategy simply overlooks individual and communal welfare perspectives, as well as ethical considerations regarding nature and the environment, unintentionally endorsing perspectives conflicting with equitable and favorable futures (Chan et al., 2016).

In this scenario, strategic approaches that link science to aspects of daily life can be a powerful and useful instrument. Some basic examples include framing or relating climate change to air pollution (Hart and Feldman, 2021) or exploring how noise and water pollution affect the lives of marine animals, such as dolphins and other mammals inhabiting ecosystems near urban centers (Maciel et al., 2023; Alzola-Andres et al., 2024). Thus, incorporating media literacy and emphasizing real-world connections offers a pragmatic pathway forward. However, many non-scientists simply do not associate that this kind of assessment can be both directly and indirectly applied in biodiversity conservation and public health issues. For instance, migratory whale behavior may shed light on climate change effects (Learmonth et al., 2006), on the transportation of parasites from one part of the globe to another (Bauer and Hoye, 2014), and on the chemical contamination these animals, their prey, and other trophic web components, are exposed to (Augier et al., 1993; Gray, 2002; dos Santos et al., 2016). This, in turn, is directly relatable to Public Health issues if the prey is shared by humans due to dietary human contamination (Di Beneditto and Siciliano, 2007), or if the dolphins themselves inhabit coastal areas, and are, thus, exposed to chemicals originated from anthropogenic activities (Cannier and West, 2005).

In a very different example, earthworm exposure to pesticides may lead to reduced earthworm populations (and other organisms), which would lead to reduced soil aeration and organic matter content, among others, resulting in decreased crop productivity (Blouin et al., 2013), clearly impacting human society as a whole.

In this framework, one scientist's field of knowledge may, and usually will, complement another's, in order to obtain a holistic view of what is taking place on our planet. Genetics, proteomics, ecotoxicology, analytical chemistry, taxonomy and systematics; these very diverse fields should, can and have begun to walk alongside each other in the search for biodiversity conservation in an integrative perspective of knowledge construction. Understanding, for example, the biochemical effects of chemical pollutants on the development, growth, reproduction, behavior and ecology of flora and fauna alike can lead to information on data deficient, vulnerable, and threatened species that will, in turn, aid in conservation efforts, as it is clear that we cannot change what we do not, first, understand. A glaring example is the fact that many biodiversity losses occur before we even know what we have lost, as the great majority of plant and animal species have not even been described yet (Pimm et al., 2014).

This integration in addressing environmental problems from a perspective of promoting Environmental Health strengthens the idea that what affects the environment will, by extension, affect humans. For instance, over half of known human pathogenic diseases can be aggravated by greenhouse gas emissions and consequent climate change effects (Mora et al., 2022). However, how and to what extent this relationship occurs is the focus of many studies, as many processes are still not understood. In addition, many scientists find it very hard to "get this point of view across," as people still like to compartmentalize knowledge, clearly separating knowledge fields and, in many instances, not linking them together to view the entire scenario. This lack of interdisciplinarity between fields has led to difficulties in implementing solid management actions for biodiversity conservation worldwide. This demands both actions and reactions, from many diverse fields, including environmental education, policy and decision-making and risk assessments, among others.

Perhaps, when the point is made and thoroughly incorporated that biodiversity losses do indeed affect humans, leading to both short and long-term effects in both the micro and the macro context, will scientists and other social actors, such as governments and policy-makers, band together in order to attempt to change our current ways and think of biodiversity preservation not only to "save the whales" as it were, but to really comprehend the global harm we have caused, are still causing, and will still cause to both our planet and, consequently, ourselves.

This requires the use of tools to reach all societal strata, not only the scientific community, as all humans have a responsibility toward planetary health and in avoiding unjust planetary changes (Humphreys, 2023). This can be achieved by applying Scientific Communication and Scientific Literacy (SL) tools.

Scientific communication and scientific literacy (SL)

Scientific communication, scientific literacy and science or biological education occupies a central position in expanding the importance that society attributes to scientific research, technological development and the public's perception of the benefits and risks of science, as well as how to guarantee science-public-media-politics interface relationships (Azevedo and Marques, 2017; Kappel and Holmen, 2019; Ochu et al., 2022; Rushton and Walshe, 2022).

Scientific dissemination employs tools for democratizing scientific knowledge other than those applied in scientific papers, which are commonly restricted to academia and disclosed in a way clearly not suitable for the lay public (Ivanissevich, 2009). When the particular process of scientific dissemination creates a more direct relationship between sources and the public, dispensing mediation, interaction is more easily enhanced and the quality of information is preserved (Bueno, 2010). Thus, knowledge socialization and popularization must be considered a mission for scientists, who must approach the lay population through different strategies.

Communicating science to the public assumes an urgency to engage and reach these people with messages that convey the impact, importance and excitement of science (Campbell, 2017). However, the science-society relationship experiences significant turmoil when advances or scientific discoveries collide with religious beliefs, fundamental human values, long-held views and populism, among other critical aspects (National Academies of Sciences, Engineering, and Medicine, 2017; Mede and Schafer, 2020). Burns and colleagues, for example, argue that scientific communication results and responses occur in the "real world" rather than under the controlled conditions of a research laboratory (Burns et al., 2003). In this context, the authors propose the following definition of scientific communication:

> *"SCIENCE COMMUNICATION (SciCom) may be defined as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the vowel analogy).*
>
> ***A**wareness, including familiarity with new aspects of science.*
>
> ***E**njoyment or other affective responses,* e.g., *appreciating science as entertainment or art.*
>
> ***I**nterest, as evidenced by voluntary involvement with science or its communication.*
>
> ***O**pinions, the forming, reforming, or confirming of science-related attitudes.*
>
> ***U**nderstanding of science, its content, processes, and social factors.*
>
> *Science communication may involve science practitioners, mediators, and other members of the general public, either peer-to-peer or between groups."*

According to Campbell, four principles should be considered for science communication to be more effective: (a) *Understand the audience*; (b) *Tell good stories*; (c) *Speak plainly*; and (d) *Play the long game* (maintain a consistent commitment to ongoing outreach and relationship-building with the public) (Campbell, 2017).

Diversifying strategies and tools for environmental and scientific literacy

In the current context, it is crucial to recognize that the influence of social media platforms on the relationship between science and the public deserves attention (Vosoughi et al., 2018; Knudsen et al., 2022). According to Dietmar Höettecke and Douglas Allchin, as individuals increasingly turn to social media as their main source of scientific information, the Nature of Science (NOS) education should also address science communication, involving the mediation, mechanisms, and manipulation involved in disseminating scientific knowledge, encompassing more than just understanding the scientific process (Hoettecke and Allchin, 2020).

Digital communication platforms present further opportunities, such as higher visibility for different research topics and advances, contributing to popularizing access to scientific knowledge (Lopes et al., 2017; Paola et al., 2022). Social media, for example, have been increasingly indicated as valuable tools in several fields of interest, such as in wildlife conservation, among others (Wu et al., 2018; Toivonen et al., 2019; Soriano-Redondo et al., 2023). Some challenges for science communication and education on the web are, however, are also noted (Kennett et al., 2015; Welbourne and Grant, 2016; Lopes et al., 2017; Fahnrich et al., 2021; Ochu et al., 2022), such as inappropriate scientific dissemination (Wu et al., 2018) and limited access to systematic organization, marketing, commitment and skills, making this type of approach focused mainly on developed countries (Kennett et al., 2015).

Communication in social networks must, therefore, follow inclusive strategies for the lay public in discussions on relevant scientific themes. Most of the general public encompasses consumers of third party-generated content which are, in turn, susceptible to emotional responses driven by content creators looking for profit online (Horner et al., 2021). This is where the scientific communicator's relevance comes into effect, elaborating content opposing disinformation sources and making them attractive and respectful to the public.

It is also important to note the role of the huge communication networks, such as British Broadcasting Corporation (BBC) and Deutsche Welle (DW), among other official broadcast channels from governments whose relevance can be verified by the explanatory videos these companies produce and share in the social networks, with many of these focusing on scientific communication (Pérez and Romanini, 2022). Although they are not produced by scientists, their content is the result of serious work conducted by journalists interested in sharing appropriate knowledge to their audiences. These actors base their content on scientific produced knowledge, presenting their sources, interviewing specialists and creating ways of transforming specialized knowledge discovered by scientists into more easily accessible knowledge by using techniques such as infographics, audios and games.

A first SL movement should be carried out in the sense of educating the public in identifying reliable sources of information, which is directed related to the required Skills for understanding how science works, in a digital media context, in order to increase the dissemination of reliable information on social networks. Once the public grasps this basic knowledge, it becomes possible to invite it to actively participate in the debates surrounding a main topic, through Activities and Dialogue. Being a specialist is not required for participation in any debate, but it is important to demonstrate that science is built from successive dialogue and debates that pave the way for knowledge advancement in all knowledge areas.

To improve critical sense and understanding to build a desirable degree of confidence in scientific information, it is essential to understand the scientific method from the beginning of schooling. Thus, even though scientific information is easily available, we still face the challenge of critically analyzing the information. This competence allows us to differentiate what comes from consolidated research approved by peers, from misinformation (sometimes calculated to deceive us) (Allchin, 2023). In this way, the school model has been transforming in the sense of not only teaching scientific concepts, but also teaching how to identify information and classify it as reliable or not (Kovacs and Tinoca, 2017).

A clear example of this were the discussions concerning the vaccine efficiency during the COVID-19 pandemic on social networks, which in many ways kept the public away from the benefits of immunization (Scannell et al., 2021). The same effect is moving public opinion on climate change issues, whose effects are direct consequences of human actions with disastrous consequences on biodiversity. Societal awareness and consequent efforts to mitigate climate change effects would be much more efficient if the public were able to recognize and distinguish between adequate and true sources of information and the quality of the presented information, as well as, mainly, to comprehend the scientific knowledge generation process.

For example, two separate studies observed that climate scientists exhibit heightened emotional intensity toward climate change compared to both students and the general population. This indicates that the identification of "objects of care" connecting individuals to climate change may be paramount in understanding why some individuals harbor stronger sentiments on the matter than others and how emotions can spur proactive measures (Wang et al., 2018; Ray, 2020). In another assessment, a global survey assessed climate anxiety in 10,000 children and young people and their beliefs about government responses to climate change in Australia, Brazil, Finland, France, India, Nigeria, Philippines, Portugal, the UK, and the USA (Hickman et al., 2021). The findings indicate that 59% of the participants expressed significant concern and 84% were at least moderately worried, while over 50% reported experiencing emotions such as sadness, anxiety, anger, powerlessness, helplessness, and guilt, over 45% noted that their sentiments toward climate change had a detrimental impact on their daily life and functioning, and a substantial number reported a prevalence of negative thoughts about climate change. Moreover, respondents expressed unfavorable views of governmental responses to climate change, highlighting a greater sense of betrayal than reassurance. A correlation between climate anxiety and distress and the perception of inadequate government response was also observed, leading to heightened feelings of betrayal, which could be mitigated by adequate scientific communication efforts. In a third study, a qualitative assessment evaluated the Brazilian children and adolescents regarding climate change, aiming to provide insights for environmental education, communication, and self-care strategies tailored to this age group, particularly in low-and middle-income countries (Chou et al., 2023). Three distinct profiles were determined concerning climate change involvement: unaware, disengaged, and engaged, all of which exhibited strong associations with diverse socioeconomic contexts. Participants depicted adults as either stubborn deniers, neutral influences, or role models of knowledge and engagement. Notably, young children, owing to their age and developmental stage, demonstrated unique climate change perceptions. The authors indicate that crafting effective communication strategies to promote climate action at both individual and collective levels necessitates narratives tailored to different age groups.

Scientific literacy, carried out in different spaces, transforms human relationships and adds value to certain processes, such as social equality, increasing the engagement of individuals to understand and intervene in the search for solutions to the complex problems that humanity faces today (Valladares, 2021). Therefore, SL should be an important schooling outcome and a consensus goal for science education, involving a multitude of intellectual resources, including the ability to conceptualize phenomena and reason from a scientific epistemology and build scientific ideas and arguments consistent with those of the scientific community, by analyzing and interpreting data and evidence consistently and adequately (Brown et al., 2005). In this sense, museums, educational centers and developing education and communication interventions using simple and practical educational tools also display significant potential for the promotion of environmental and scientific literacy, as well as in addressing scientific misconceptions, controversial topics and dismissing fake news (de los Santos et al., 2018; Bevilaqua et al., 2020; Suarez-Fontes et al., 2022; Suldovsky et al., 2022). These actions can also comprise an efficient strategy to select structuring concepts and themes from the Natural Sciences for the development of scientific literacy processes, such as the theory of biological evolution and/or basic paleontology concept, among others (Estrup and Achiam, 2019; Plutzer et al., 2020).

We consider and agree with other authors that scientific literacy is a collective activity property, and not of individual minds, and that scientific education must be developed for an emancipatory process of individuals, making citizens capable of a constructive participation in community life (Roth and Lee, 2002, 2004; Roth, 2007; Bassiano and de Lima, 2018). This is especially true given that most adults receive formal education in science only during compulsory schooling, so the knowledge acquired through informal learning and experiences beyond mandatory education plays a crucial role in shaping the scientific literacy of individuals (Reis et al., 2014). In this context, teaching and learning activities on how anthropic action affect ecosystem structure and functioning, through strategies or methodologies such as Problem-Based Learning, Project-Based Learning and Problematization, as well as through social media and through museums and educational centers can directly contribute to SL and build a participatory democracy to improve the quality of socio-environmental determinants, leading to environmental and human health promotion (Freire, 1989; Glassman and Patton, 2014; Lewinsohn et al., 2015; McGibbon and Van Belle, 2015; Darr et al., 2020; Lopes et al., 2020).

In this sense, one study assessed the effectiveness of three iterations of an exhibit focused on deep-sea ecosystem services and habitats that served as a valuable tool for enhancing scientific literacy for fostering understanding and responsible decision-making among diverse audiences by observing visitor interactions and conducting surveys (Darr et al., 2020). The authors report that exhibits incorporating video and interactive components emerged as successful in conveying deep-sea information, and this knowledge was retained by visitors over an extended period, with visitors tending to align with protection-oriented value statements and show less agreement with use-oriented value statements regarding the deep sea. A similar study verified stable episodic memories of science exhibits in science centers in the general adult population regardless of whether they had discussed the exhibit extensively during the initial interview with the interviewer (Medved and Oatley, 2000). All participants expressed affective involvement during both interviews, with happiness being the most prevalent, followed by curiosity. Additionally, a noteworthy one-third of the participants mentioned linking exhibit memories to everyday events, indicating an increased awareness of scientific phenomena. Furthermore, one study regarding visitors to a museum's Earth sciences exhibitions indicated that nearly half of the respondents of an applied questionnaire (46.67%) reported an increased interest in Geology following their visit, while almost all (92.67%) stated that their geological knowledge had expanded (Reis et al., 2010), further corroborating the effectiveness of learning in in out-of-school settings. Finally, one two-year study assessed a collaboration between a university and a museum where 81 preservice teachers engaged with sixth-grade students on a weekly basis within a museum environment (Hamilton and Van Duinen, 2021). The authors report indicate that this hybrid setting allowed preservice teachers to broaden their understanding of literacy and text, while also facilitating the expansion and enrichment of sixth-graders' connections to the curriculum, also creating novel opportunities to reconsider adolescents' roles as learners, including the reimagining of secondary students as educators.

On the other hand, understanding certain teaching strategies is not enough. It is also necessary to reflect on SL approaches in a school context. In this scenario, education for sustainability emerges as an alternative to current and widely applied reductionist model of science teaching, whose focus is simply on knowledge transmission and case analyses, which are rarely linked to student day-to-day lives and worries. The approach of an education toward sustainability points to important ways to elucidate environmental issues, highlighting from the start that they have a solution, pursuing the development of a perspective for coping ability and distancing students from feelings of passivity or incapacity, which may worsen information refusal in the long run (Hicks and Holden, 1995; Acevedo et al., 2022). Thus, applying SL as an approach based on the pillars of sustainability, we may avoid the promotion of teaching that seeks to restrict environmental issues to natural preservation and conservation aspects, while promoting the incorporation of social aspects into the relationships linking anthropic action and environmental effects (Tilbury, 1995; Vesterinen et al., 2016).

Although the concept of sustainability has been under constant debate for years (Hopwood et al., 2005), the defense of an educational approach to sustainability should not be associated to a "vision," often used in political discourse, of sustainable development to justify the continuity of a production and economic growth relationship that externalizes – or does not relate to political and citizen action – the consequences of environmental degradation and, therefore, is essentially unsustainable (Vilches et al., 2011). Education for sustainability is clearly and indubitably more than environmental education. It is the result of scientific education evolution and plays an important social contribution in dealing with major contemporary ecological issues, instead of being based solely on the study of science for environmental protection (Acosta Castellanos and Queiruga-Dios, 2022; Li et al., 2023).

Finally, the emergence of movements running in parallel with efforts in science teaching area must also be considered. These movements favor disbelief and lack of social engagement in relation to environmental conditions and their consequences for life on Earth, sometimes even intentionally. Influential disinformation campaigns and fabricated controversies have manipulated scientific knowledge through people viewpoints, seeding confusion and threatening to derail environmental progress (Fake News Threatens a Climate Literate World, 2017). The clearest example of this is climate change. Abundant scientific studies have proven that climate change is a scientific fact. However, climate change and its severity provide psychological reasons for people to allow themselves to believe in fake news that distort or deny the climate change reality. As this is often presented as bad news, both in formal contexts and in science communication articles, many people prefer not to face the problem. It, unfortunately, becomes more attractive to believe that climate scientists are falsifying their studies to enrich themselves by promoting the "climate change industry" (Miller, 2019). This becomes a significant obstacle in understanding that many of the health context changes taking place in the 21st century (as noted for the COVID-19 syndemic), is directly associated to what we scientists are promoting in terms of environmental destruction as a society, and as a challenge for SL.

Final considerations

Prioritizing scientific literacy and effective communication is imperative to bridge the gap between the scientific community and the wider public. Doing this enables the empowerment of individuals in understanding the far-reaching consequences of environmental degradation on human health, encouraging informed decisions and collective actions for a sustainable future.

In this context, interdisciplinary collaboration and the integration of environmental and social aspects in education have become paramount in building a society that recognizes its responsibility for planetary health. Overcoming the hurdles posed by disinformation campaigns, particularly in a climate change context, is equally essential to foster a global understanding of the urgent need for change.

In the face of these challenges, scientists, educators, and communicators must work collectively to disseminate accurate information, promote critical thinking, and inspire engagement, as only through such concerted efforts may we hope to address the pressing issues of biodiversity loss, environmental degradation, and their profound impacts on human well-being.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

RL: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Visualization. MC: Writing – original draft, Writing – review & editing. MP: Writing – original draft, Writing – review & editing. RS: Writing – original draft, Writing – review & editing. RH-D: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing, Supervision.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the Carlos Chagas Filho Foundation for Research Support of the State of Rio de Janeiro (FAPERJ), through a Jovem Cientista do Nosso Estado 2021–2024 grant (process number E-26/201.270/2021), Jovem Pesquisador Fluminense com Vínculo em ICTS do Estado do Rio de Janeiro grant (process number E-26/2010.300/2022), Jovem Cientista Mulher com vínculo em ICTS do Estado do RJ 2023–2026 grant (process number E-26/210.059/2024), and the Brazilian National Council of Scientific and Technological Development (CNPq), through a productivity grant (process number 308811/2021–6). The implementation of the Projeto Pesquisa Marinha e Pesqueira is a compensatory measure established by the Conduct Adjustment Agreement under the responsibility of the PRIO company, conducted by the Federal Public Ministry-MPF/RJ.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

References

Acevedo, B., Malevicius, R., Fadli, H., and Lamberti, C. (2022). Aesthetics and education for sustainability. *Cult. Organ.* 28, 263–278. doi: 10.1080/14759551.2022.2028147

Acosta Castellanos, P. M., and Queiruga-Dios, A. (2022). From environmental education to education for sustainable development in higher education: a systematic review. *Int. J. Sustain. High. Educ.* 23, 622–644. doi: 10.1108/IJSHE-04-2021-0167

Allchin, D. (2023). Ten competencies for the science misinformation crisis. *Sci. Educ.* 107, 261–274. doi: 10.1002/sce.21746

Alzola-Andres, M., Cerveny, D., Domingo-Echaburu, S., Lekube, X., Ruiz-Sancho, L., Brodin, T., et al. (2024). Pharmaceutical residues in stranded dolphins in the Bay of Biscay. *Sci. Total Environ.* 912:168570. doi: 10.1016/j.scitotenv.2023.168570

Augier, H., Park, W. K., and Ronneau, C. (1993). Mercury contamination of the striped dolphin stenella-coeruleoalba meyen from the french mediterranean coasts. *Marine Pollution Bulletin*, 26, 306–310. doi: 10.1016/0025-326x(93)90572-2

Azevedo, J., and Marques, M. (2017). Climate literacy: a systematic review and model integration. *Int. J. Glob. Warming* 12, 414–430. doi: 10.1504/ijgw.2017.10005893

Ballester, J., Quijal-Zamorano, M., Turrubiates, R. F. M., Pegenaute, F., Herrmann, F. R., Robine, J. M., et al. (2023). Heat-related mortality in Europe during the summer of 2022. *Nat. Med.* 29:1857-+. doi: 10.1038/s41591-023-02419-z

Bassiano, V., and de Lima, C. A. (2018). Emancipatory education in the perspective of Paulo Freire. *Revista De Pedagogia Universitaria Y Didactica Del Derecho* 5, 111–122. doi: 10.5354/0719-5885.2017.51974

Bauer, S., and Hoye, B. J. (2014). Migratory animals couple biodiversity and ecosystem functioning worldwide. *Science* 344:54-+. doi: 10.1126/science.1242552

Bevilaqua, D. V., Gonzalez, A. C. D., Mano, S. M. F., Guimaraes, V. F., and de Almeida, W. D. (2020). Rio de Janeiro's Museu da Vida and its publics: reflections on influence zone and the social role of a science museum. *Em Questao* 26, 276–297. doi: 10.19132/1808-5245263.276-297

Bhore, S. J. (2016). Global goals and global sustainability. *Int. J. Environ. Res. Public Health* 13, 1–2. doi: 10.3390/ijerph13100991

Blouin, M., Hodson, M. E., Delgado, E. A., Baker, G., Brussaard, L., Butt, K. R., et al. (2013). A review of earthworm impact on soil function and ecosystem services. *Eur. J. Soil Sci.* 64, 161–182. doi: 10.1111/ejss.12025

Brown, B. A., Reveles, J. M., and Kelly, G. J. (2005). Scientific literacy and discursive identity: A theoretical framework for understanding science learning. *Sci. Educ.* 89, 779–802. doi: 10.1002/sce.20069

Bueno, W. C. (2010). Comunicação científica e divulgação científica: aproximações e rupturas conceituais. *Informação Informação* 15, 1–12. doi: 10.5433/1981-8920.2010v15nesp.p1

Burns, T. W., O'Connor, D. J., and Stocklmayer, S. M. (2003). Science communication: a contemporary definition. *Public Underst. Sci.* 12, 183–202. doi: 10.1177/09636625030122004

Campbell, A. A. (2017). Communicating science effectively to the public. *Chem. Eng. News* 95:34.

Cannier, A., and West, K. L. (2005). Distribution of the rough-toothed dolphin (*Steno bredanensis*) around the Windward Islands (French Polynesia). *Pac. Sci.* 59, 17–24. doi: 10.1353/psc.2005.0007

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., Garcia, A., Pringle, R. M., and Palmer, T. M. (2015). Accelerated modern human-induced species losses: entering the sixth mass extinction. *Sci. Adv.* 1:e1400253. doi: 10.1126/sciadv.1400253

Chan, K. M. A., Balvanera, P., Benessaiah, K., and Turner, N. (2016). Why protect nature? Rethinking values and the environment. *Proc. Natl. Acad. Sci. U. S. A.* 113, 1462–1465. doi: 10.1073/pnas.1525002113

Chou, D. T., Neto, E. A., Thomas, I., Martin, A., and Benoit, L. (2023). Climate awareness, anxiety, and actions among youth: a qualitative study in a middle-income country. *Brazilian J. Psychiatry* 45, 258–267. doi: 10.47626/1516-4446-2022-2890

Darr, K. D., East, J. L., Seabrook, S., Dundas, S. J., and Thurber, A. R. (2020). The Deep Sea and me: using a science center exhibit to promote lasting public literacy and elucidate public perception of the Deep Sea. *Front. Mar. Sci.* 7:159. doi: 10.3389/fmars.2020.00159

de los Santos, T. M., Smith, E., and Cohen, M. (2018). Targeting truth: how museums can collaboratively address social issues. *J. Mus. Educ.* 43, 104–113. doi: 10.1080/10598650.2018.1457842

Di Beneditto, A. P. M., and Siciliano, S. (2007). Stomach contents of the marine tucuxi dolphin (*Sotalia guianensis*) from Rio de Janeiro, South-Eastern Brazil. *J. Mar. Biol. Assoc.* 87, 253–254. doi: 10.1017/s0025315407053647

Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J. B., and Collen, B. (2014). Defaunation in the Anthropocene. *Science* 345, 401–406. doi: 10.1126/science.1251817

dos Santos, D. R., Yamamoto, F. Y., Neto, F. F., Randi, M. A. F., Garcia, J. E., Costa, D. D. M., et al. (2016). The applied indicators of water quality may underestimate the risk of chemical exposure to human population in reservoirs utilized for human supply-southern Brazil. *Environ. Sci. Pollut. Res.* 23, 9625–9639. doi: 10.1007/s11356-015-5995-0

Edenborg, E. (2022). Disinformation and gendered boundarymaking: Nordic media audiences making sense of "Swedish decline". *Coop. Confl.* 57, 496–515. doi: 10.1177/00108367211059445

Estrup, E. J., and Achiam, M. (2019). The potential of palaeontology for science education. *Nordic Stud. Sci. Educ.* 15, 97–108. doi: 10.5617/nordina.5253

Fahnrich, B., Wilkinson, C., Weitkamp, E., Heintz, L., Ridgway, A., and Milani, E. (2021). RETHINKING science communication education and training: towards a competence model for science communication. *Front. Commun.* 6:795198. doi: 10.3389/fcomm.2021.795198

Fake News Threatens a Climate Literate World (2017). Fake news threatens a climate literate world. *Nat. Commun.* 8:15460. doi: 10.1038/ncomms15460

Fasce, A., and Pico, A. (2019). Science as a vaccine: the relation between scientific literacy and unwarranted beliefs. *Sci. Educ.* 28, 109–125. doi: 10.1007/s11191-018-00022-0

Freire, P. (1989). *Educação como prática da liberdade* (*19a ed.*). Rio de Janeiro: Paz e Terra.

Glassman, M., and Patton, R. (2014). Capability through participatory democracy: Sen, Freire, and Dewey. *Educ. Philos. Theory* 46, 1353–1365. doi: 10.1080/00131857.2013.828582

Gray, J. S. (2002). Biomagnification in marine systems: the perspective of an ecologist. *Marine Pollution Bulletin*, 45, 46–52. doi: 10.1016/s0025-326x(01)00323-x

Gupta, M., Dennehy, D., Parra, C. M., Mäntymäki, M., and Dwivedi, Y. K. (2023). Fake news believability: the effects of political beliefs and espoused cultural values. *Inf. Manag.* 60:103745. doi: 10.1016/j.im.2022.103745

Hamilton, E. R., and Van Duinen, D. V. (2021). Hybrid spaces: adolescent literacy and learning in a museum. *J. Adolesc. Adult. Lit.* 64, 511–520. doi: 10.1002/jaal.1123

Harker-Schuch, I., Lade, S., Mills, F., and Colvin, R. (2021). Opinions of 12 to 13-year-olds in Austria and Australia on the concern, cause and imminence of climate change. *Ambio* 50, 644–660. doi: 10.1007/s13280-020-01356-2

Harsin, J. (2020). Toxic white masculinity, post-truth politics and the COVID-19 infodemic. *Eur. J. Cult. Stud.* 23, 1060–1068. doi: 10.1177/1367549420944934

Hart, P. S., and Feldman, L. (2021). The benefit of focusing on air pollution instead of climate change: how discussing power plant emissions in the context of air pollution, rather than climate change, influences perceived benefits, costs, and political action for policies to limit emissions. *Sci. Commun.* 43, 199–224. doi: 10.1177/1075547020980443

Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R. E., Mayall, E. E., et al. (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. *Lancet Planetary Health* 5, E863–E873. doi: 10.1016/S2542-5196(21)00278-3

Hicks, D., and Holden, C. (1995). Exploring the future: a missing dimension in environmental education. *Environ. Educ. Res.* 1, 185–193. doi: 10.1080/1350462950010205

Hoettecke, D., and Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Sci. Educ.* 104, 641–666. doi: 10.1002/sce.21575

Hopwood, B., Mellor, M., and O'Brien, G. (2005). Sustainable development: mapping different approaches. *Sustain. Dev.* 13, 38–52. doi: 10.1002/sd.244

Horner, C. G., Galletta, D., Crawford, J., and Shirsat, A. (2021). Emotions: the unexplored fuel of fake news on social media. *J. Manag. Inf. Syst.* 38, 1039–1066. doi: 10.1080/07421222.2021.1990610

Horton, R. (2020). Offline: after COVID-19-is an "alternate society" possible? *Lancet* 395:1682. doi: 10.1016/S0140-6736(20)31241-1

Humphreys, S. (2023). How to identify unjust planetary change. *Nature* 619, 35–36. doi: 10.1038/d41586-023-01743-1

Imazon (2023). Amazon Institute of People and Environment. Available at: https://imazon.org.br/imprensa/desmatamento-na-amazonia-cresce-7-e-tem-o-pior-fevereiro-em-16-anos/

Ivanissevich, A. (2009). A missão de divulgar Ciência no Brasil. *Ciência e Cultura* 61, 4–5.

Kappel, K., and Holmen, S. J. (2019). Why science communication, and does it work? A taxonomy of science communication aims and a survey of the empirical evidence. *Front. Commun.* 4:55. doi: 10.3389/fcomm.2019.00055

Kennett, R., Danielsen, F., and Silvius, K. M. (2015). Citizen science is not enough on its own. *Nature* 521:161. doi: 10.1038/521161d

Knudsen, E., Dahlberg, S., Iversen, M. H., Johannesson, M. P., and Nygaard, S. (2022). How the public understands news media trust: an open-ended approach. *Journalism* 23, 2347–2363. doi: 10.1177/14648849211005892

Kovacs, H., and Tinoca, L. (2017). Unfreeze the pedagogies: introduction of a new innovative measure in Portugal. *Revista Tempos E Espacos Educacao* 10, 73–86. doi: 10.20952/revtee.v10i23.7446

Lancet, T. (2024). Viruses, bacteria, vectors, and climate change: how worried should the Americas be? *Lancet Regional Health Americas* 29:100675. doi: 10.1016/j.lana.2024.100675

Layman, R. C., Boyce, J. R., and Criddle, K. R. (1996). Economic valuation of the Chinook Salmon sport fishery of the Gulkana River, Alaska under current and alternate management plans. *Land Econ.* 72, 113–128. doi: 10.2307/3147161

Learmonth, J. A., Mac Leod, C. D., Santos, M. B., Pierce, G. J., Crick, H. Q. P., and Robinson, R. A. (2006). Potential effects of climate change on marine mammals. *Oceanogr. Mar. Biol.* 44, 431–464. doi: 10.1201/9781420006391.ch8

Lewinsohn, T. M., Attayde, J. L., Fonseca, C. R., Ganade, G., Jorge, L. R., Kollmann, J., et al. (2015). Ecological literacy and beyond: problem-based learning for future professionals. *Ambio* 44, 154–162. doi: 10.1007/s13280-014-0539-2

Li, B., Sjöström, J., Ding, B., and Eilks, I. (2023). Education for sustainability meets Confucianism in science education. *Sci. Educ.* 32, 879–908. doi: 10.1007/s11191-022-00349-9

Lopes, R. M., de Faria, D., Fidalgo-Neto, A. A., and Mota, F. B. (2017). Facebook in educational research: a bibliometric analysis. *Scientometrics* 111, 1591–1621. doi: 10.1007/s11192-017-2294-1

Lopes, R. M., Hauser-Davis, R. A., Oliveira, M. M., Pierini, M. F., de Souza, C. A. M., Cavalcante, A. L. M., et al. (2020). Principles of problem-based learning for training and professional practice in ecotoxicology. *Sci. Total Environ.* 702:134809. doi: 10.1016/j.scitotenv.2019.134809

Maciel, I., Belderrain, T., Alves, M. A. S., and Tardin, R. (2023). Stay here, but keep quiet: the effects of anthropogenic noise on Guiana dolphins (*Sotalia guianensis*) in southeastern Brazil. *Mar. Biol.* 170:16. doi: 10.1007/s00227-023-04312-2

McGibbon, C., and Van Belle, J. P. (2015). Integrating environmental sustainability issues into the curriculum through problem-based and project-based learning: a case study at the University of Cape Town. *Curr. Opin. Environ. Sustain.* 16, 81–88. doi: 10.1016/j.cosust.2015.07.013

Mede, N. G., and Schafer, M. S. (2020). Science-related populism: conceptualizing populist demands toward science. *Public Underst. Sci.* 29, 473–491. doi: 10.1177/0963662520924259

Medved, M. I., and Oatley, K. (2000). Memories and scientific literacy: remembering exhibits from a science Centre. *Int. J. Sci. Educ.* 22, 1117–1132. doi: 10.1080/095006900429475

Miller, M. (2019). *Fake news: separating truth from fiction* Twenty-First Century Books™. Minneapolis.

Mora, C., McKenzie, T., Gaw, I. M., Dean, J. M., Von Hammerstein, H., Knudson, T. A., et al. (2022). Over half of known human pathogenic diseases can be aggravated by climate change. Nature. *Climate Change* 12:869-+. doi: 10.1038/s41558-022-01426-1

National Academies of Sciences, Engineering, and Medicine (2017). *Communicating science effectively: a research agenda*. Washington, DC: The National Academies Press.

Ochu, E., Russo, P., and Smeets, L. (2022). "The future is now" - a European perspective on the future of science communication. *J. Sci. Commun.* 21:5. doi: 10.22323/2.21050603

Paola, V. S., Brenda, F. R., Angelica, A. V. M., Jorge, I. E., Fernando, G. N. F., and Antonio, A. V. R. (2022). Analysis of scientific dissemination posts on Facebook from a social media approach. Paper presented at the 17th Iberian conference on information systems and technologies (CISTI), Madrid, Spain.

Pérez, G., and Romanini, V. (2022). The role of television journalism in the production of political narratives: a comparative study Brazil/Colombia. *Brazilian J. Res.* 18, 64–91. doi: 10.25200/BJR.v18n1.2022.1398

Perez-Mendez, N., Jordano, P., Garcia, C., and Valido, A. (2016). The signatures of Anthropocene defaunation: cascading effects of the seed dispersal collapse. *Scientific Reports*, 6. doi: 10.1038/srep24820

Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., et al. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344:987. doi: 10.1126/science.1246752

Plutzer, E., Branch, G., and Reid, A. (2020). Teaching evolution in U.S. public schools: a continuing challenge. *Evo. Edu. Outreach* 13, 14–15. doi: 10.1186/s12052-020-00126-8

Ray, S. J. (2020). *A field guide to climate anxiety: how to keep your cool on a warming planet*. University of California Press.

Reis, J., Brilha, J., Barriga, F., Lopes, C., and Povoas, L. (2010). "O Museu Nacional de História Natural como promotor do Património Geológico: caracterização preliminar dos visitantes do Departamento de Mineralogia e Geologia" in *Colecções e Museus de Geologia: Missão e Gestão*. eds. J. M. Brandão, P. Callapez, O. Mateus and P. Castro (Coimbra: Museu Mineralógico e Geológico da Universidade de Coimbra (MMGUC), Centro de Estudos de História e filosofia da Ciência (CEHFCi)), 369–376.

Reis, J., Póvoas, L., Barriga, F., Lopes, C., Santos, V. F., Ribeiro, B., et al. (2014). Science education in a museum: enhancing earth sciences literacy as a way to enhance public awareness of geological heritage. *Geoheritage* 6, 217–223. doi: 10.1007/s12371-014-0105-0

Romanelli, C., Cooper, D., Campbell-Lendrum, D., Maiero, M., Karesh, W. B., Hunter, D., et al. (2015). *Connecting global priorities: Biodiversity and human health: A state of knowledge review. In (pp. 344): World Health Organization and secretariat of the convention on biological diversity*. World Health Organization.

Roth, W. M. (2007). Toward a dialectical notion and praxis of scientific literacy. *J. Curric. Stud.* 39, 377–398. doi: 10.1080/00220270601032025

Roth, W. M., and Lee, S. (2002). Scientific literacy as collective praxis. *Public Underst. Sci.* 11, 33–56. doi: 10.1088/0963-6625/11/1/302

Roth, W. M., and Lee, S. (2004). Science education as/for participation in the community. *Sci. Educ.* 88, 263–291. doi: 10.1002/sce.10113

Rushton, E. A. C., and Walshe, N. (2022). Climate change, sustainability and the environment: the continued importance of biological education. *J. Biol. Educ.* 56, 243–244. doi: 10.1080/00219266.2022.2116843

Scannell, D., Desens, L., Guadagno, M., Tra, Y., Acker, E., Sheridan, K., et al. (2021). COVID-19 vaccine discourse on twitter: A content analysis of persuasion techniques, sentiment and Mis/disinformation. *J. Health Commun.* 26, 443–459. doi: 10.1080/10810730.2021.1955050

Soriano-Redondo, A., Correia, R. A., and Di Minin, E. (2023). Social media data can inform the global biodiversity framework. *Biol. Conserv.* 281:109993. doi: 10.1016/j.biocon.2023.109993

Suarez-Fontes, A. M., Almeida-Silva, J., Fontes, S. S., Silva, S. C. S., and Vannier-Santos, M. A. (2022). Climate changes: fact or fake? Low-cost hands-on experiments to Verify it. *Creat. Educ.* 13, 3642–3662. doi: 10.4236/ce.2022.1311232

Suldovsky, B., Allison, M., Joubert, M., Lofgren, I. E., and McWilliams, S. (2022). Editorial: helping scientists to communicate well for all considered: strategic science communication in an age of environmental and health crises. *Front. Commun.* 7:970331. doi: 10.3389/fcomm.2022.970331

Sunyík, V., and Cavojová, V. (2023). Alternative medicine, COVID-19 conspiracies, and other health-related unfounded beliefs: the role of scientific literacy, analytical thinking, and importance of epistemic rationality. *Stud. Psychol.* 65, 246–261. doi: 10.31577/sp.2023.03.878

Tilbury, D. (1995). Environmental education for sustainability: defining the new focus of environmental education in the 1990s. *Environ. Educ. Res.* 1, 195–212. doi: 10.1080/1350462950010206

Toivonen, T., Heikinheimo, V., Fink, C., Hausmann, A., Hiippala, T., Jarv, O., et al. (2019). Social media data for conservation science: a methodological overview. *Biol. Conserv.* 233, 298–315. doi: 10.1016/j.biocon.2019.01.023

UN (2015). *Transforming our world: the 2030 agenda for sustainable development*. United Nations.

Valladares, L. (2021). Scientific Literacy and Social Transformation Critical Perspectives About Science Participation and Emancipation. *Science \u0026amp; Education*, 30, 557–587. doi: 10.1007/s11191-021-00205-2

Vesterinen, V. M., Tolppanen, S., and Aksela, M. (2016). Toward citizenship science education: what students do to make the world a better place? *Int. J. Sci. Educ.* 38, 30–50. doi: 10.1080/09500693.2015.1125035

Vilches, A., Pérez, D. G., and Praia, J. (2011). "De CTS a CTSA: educação por um futuro sustentável" in *CTS e Educação científica: desafios, tendências e resultados de pesquisa*. eds. W. L. P. D. Santos and D. Auler (Brasília: Editora Universidade de Brasília), 161–184.

Vosoughi, S., Roy, D., and Aral, S. (2018). The spread of true and false news online. *Science* 359:1146. doi: 10.1126/science.aap9559

Wang, S., Leviston, Z., Hurlstone, M., Lawrence, C., and Walker, L. (2018). Emotions predict policy support: why it matters how people feel about climate change. *Glob. Environ. Change Hum. Policy Dimensions* 50, 25–40. doi: 10.1016/j.gloenvcha.2018.03.002

Welbourne, D. J., and Grant, W. J. (2016). Science communication on YouTube: factors that affect channel and video popularity. *Public Underst. Sci.* 25, 706–718. doi: 10.1177/0963662515572068

Wu, Y. L., Xie, L., Huang, S. L., Li, P., Yuan, Z. W., and Liu, W. H. (2018). Using social media to strengthen public awareness of wildlife conservation. *Ocean Coastal Manag.* 153, 76–83. doi: 10.1016/j.ocecoaman.2017.12.010