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The potential for systems thinking as an approach for evaluating false science information

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Misinformation and disinformation pose serious global risks, undermining public trust in science and hindering progress towards the UN Sustainable Development Goals. The rapid spread of information through social media and generative artificial intelligence highlights the need for education to help learners develop the capacity to critically evaluate scientific claims. This perspective proposes systems thinking (ST) as a promising pedagogical approach for empowering students to evaluate inaccurate scientific information and may be particularly useful for unpacking false claims about global challenges. ST has the potential to enable learners to recognize interconnections among components of complex global challenges so that they can reason about scientific information holistically (*e.g.*, social, political, and environmental).[1] However, ST is largely unexplored for this purpose. In this perspective, we provide a sustainability-focused pedagogical rationale for implementing ST to evaluate inaccurate scientific information and provide direction for future educational research on this topic, as no empirical evidence was collected. Empirical validation of this hypothesis is urgently required, as combating false information is essential to protecting science and accelerating progress toward the UN Sustainable Development Goals. We encourage science educators and science education researchers to explore how ST might help evaluate inaccurate scientific information. To facilitate this exploration, we provide a background of the current work that may complement future investigations, give specific examples of how ST may be applied to evaluate false information, and suggest potential research questions. Empowering future scientists and citizens to critically engage with information is essential not only for navigating false information but also for contributing to a more sustainable, informed society.

Sustainability spotlight

This perspective contributes to making progress toward Sustainable Development Goal (SDG) 4, ensuring quality education. Systems thinking has been proposed as an approach to chemistry education (and more broadly science education) to more effectively educate the next genera on of ci zens and scientists and prepare them for their roles in addressing sustainability challenges, such as those priori zed by the SDGs. There is a significant amount of false information related to global challenges (*e.g.*, climate change, vaccines) circulating in the media which can hinder progress toward the SDGS. In response, our work focuses on the urgent priority (or need) to educate students to evaluate inaccurate scientific information and unpack false claims about these global challenges that impede progress toward achieving the SDGs.

Navigating misinformation and disinformation in the age of artificial intelligence

Misinformation and disinformation are ranked the top short-term (2 year) risk and 4th long-term (10 year) risk identified by the World Economic Forum's Global Risks Perception Survey 2025–2026, capturing insights from over 900 experts worldwide.[2] Misinformation is the unintentional dissemination of inaccurate information, while disinformation is the dissemination of inaccurate information with the intention to cause harm.[3] Sometimes the term malinformation is used to describe information that is based on fact but removed from its original context and manipulated to mislead or cause harm.[4] Since misinformation, disinformation, and malinformation are all examples of false information and have the potential to cause harm, we will refer to them collectively as "false information" throughout this article. Motives for creating disinformation are complex. Immediate action is required to address the growing fake news phenomenon as its consequences are increasingly dangerous at both individual and collective levels, including: manipulated voting, decreasing vaccination rates, lack of

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masking during a pandemic, use of untested treatments, denial of anthropogenic climate change, and portrayal of ethnic groups as enemies.[5] The dissemination of deliberate and nondeliberate false information has been increasing in recent years, particularly due to the influence of social media and the growing use of artificial intelligence.[6–8] Science has been brought into the spotlight during the COVID-19 pandemic, leading to many scientists disseminating information in popular media. An infodemic (*i.e.*, a large amount of information, accurate or not) was facilitated by social media, leading to interference with disease prevention policies, undermining public trust in science, and hindering individuals' capacity to make evidence-informed choices.[5,9] In response, the World Health Organization has been training professionals to combat misinformation from this infodemic.[10]

Generative Artificial Intelligence (GenAI) has been beneficial in helping citizens and scientists summarize and generalize large amounts of existing information, and contributes toward making progress in achieving Sustainable Development Goal 4, ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all.[11] While GenAI has recently shown some promise as a preventative measure to pre-empt false information (*i.e.*, prebunking), (re)producing misinformation is reported as a high risk to education at individual, community, and system levels.[12] Thus, GenAI users need to be able to assess the quality of information produced.

Several promising initiatives to combat dis- and misinformation are being explored, including large-scale automated approaches,[13] increased responsibility by social media services,[14] and scientists speaking out when seeing false information being presented on social media.[5,15] However, when trying to correct misleading claims on social media, scientists are often constrained by word limits on the platforms, which leads to alternative approaches such as persuasive appeal, the use of quotes from scientific authority figures or illustrating single-study results as "anecdotal evidence".[16] Scientists also fight a cultural battle where the development of scientific knowledge and its processes are not well understood by the general public, leading to further misrepresentation.[17] Therefore, scientists on online platforms need to prioritize clear, evidence-based scientific information for varied audiences and work closely with non-profit, non-partisan professional science societies and organizations to identify this information.[17] Peer-reviewed scientific communication also needs to compete with non-peer-reviewed articles that convey anecdotal evidence, making it even more difficult to differentiate reliable, cumulative scientific evidence from the temporary nature of preprint findings and rogue journals.

The National Academies of Sciences, Engineering, and Medicine's recent report, *Understanding and Addressing Misinformation About Science*, provides an extensive review of recent interventions intended to address misinformation about science.[17] These misinformation interventions target multiple levels: individuals, communities, organizations, media, online platforms, and the broader information environment.[17] They also vary in their focus, targeting one or more intervention points (*e.g.*, supply, demand, distribution and uptake).[17] To date, the most understood interventions focus on individual-level strategies, including media literacy, evaluative reasoning, and debunking and target multiple intervention points.[17] While the promising initiatives and existing interventions to combat dis- and misinformation can help mitigate the spread of inaccurate information, they do not provide a long-term solution for generating a more scientifically literate society and more research is needed to further assess the effectiveness of these interventions in real-world contexts.[5,17,18] A long-term solution needs to help people develop the ability to critically examine information and judge its trustworthiness based on evidence and reasoning.[5]

Addressing the infodemic through science education

Education is considered an essential part of the long-term solution to the infodemic, in which evidence-based approaches are needed to equip learners with the knowledge, skills, and tools to be able to critically examine and assess information.[5,9,19,20] Students are a large population who are actively present on social media networks; therefore, they are highly exposed to false information. Science lessons are particularly suitable for examining misinformation and generating knowledge about global issues in which chemistry plays a vital role (*e.g.*, the COVID-19 pandemic).[6] However, formal science education does not typically address the issue of misinformation or teach science media literacy.[21] The range of science communication practices for students is small, limited to visiting extracurricular learning sites or visits of professionals and experts at school[6] and a few programs that have trained students to communicate with non-experts.[9] Students' prior knowledge plays a decisive role in identifying false information, which means their prior knowledge must be generated by suitable practices.[6] While there is widespread agreement on the need for increased science literacy across institutions, the literature presents widely divergent articulations of what it means to be scientifically literate in the 21st century and what skills students need to be equipped with to protect themselves against false information.[22]

Systems thinking as a potential approach

Systems thinking (ST) has emerged in the chemistry education literature as an approach for addressing sustainability challenges through Green and Sustainable Chemistry practices.[23–26] Global challenges are multidimensional problems of complex systems that require a systemic lens for generating solutions. Therefore, addressing these global challenges requires analyzing complex systems as a whole rather than just looking at a collection of its parts, examining the factors involved in the system along with their interactions and how those interactions lead to system behaviours that change over time.[26] If science literacy has a goal of enabling learners to identify false information on complex scientific issues, science literacy must extend beyond traditional ways of thinking about and learning science.[22] Approaches should be focused on the entire "science information lifecycle", which involves understanding how science information is generated by the scientific community, how the media disseminates this information, and how individuals access, process, and form opinions on that information.[22] For example, the committee for the National Academies of Sciences, Engineering, and Medicine's misinformation in science report utilized a systems perspective approach for examining the intersections between misinformation about science and existing risk factors and inequities, as well as the potential impacts these have on well-being.[17]

There are several ST skills reported in the literature that may be applied to evaluate false information.[27–35] The first skill is identifying the system of interest from which the false information emerges.[36] A system has (1) components/parts, (2) interconnections between the components, and (3) a purpose [or function] and can exist at multiple scales (*e.g.*, microscopic, mesoscopic, macroscopic), with the boundary conditions for the system being established by its observer.[28,37] The observer could then identify the system components and their relationships, to identify the sources, uses, and impacts of the system. Perspective-taking within the established boundary conditions can help one **consider multiple viewpoints and factors** (*e.g.*, societal, economic, environmental, political) that shape how the information is interpreted and flows among different applicable contexts (*e.g.*, the media, institutions and the public).[27,27,28,36,38,39] Next, the observer **could identify reinforcing (positive) and balancing (negative) feedback loops** to reveal how misinformation sustains or diminishes in complex systems through cause-and-effect relationships. A feedback loop is a closed circular connection between variables that affect the stability of a system.[1,30,40] A reinforcing (positive) feedback loop increases the effect of change and produces instability (*e.g.*, repeated exposure to false claims about climate change in social media increases belief in those claims, encouraging re-sharing and amplification of false narratives).[40] On the other hand, a balancing (negative) feedback loop reduces the effect of change and helps stabilize the system (*e.g.*, when trusted scientists publicly refute misinformation, they introduce corrective information that slows or reduces the spread of the false narratives – supporting more accurate information).[40] Analysis of these feedback loops could lead to the detection of recurring misinformation trends or patterns. Lastly, one could **identify leverage points** (*e.g.*, effective points of intervention to influence system behaviour) in the system of interest.[30] These leverage points can reveal where small shifts in strategic actions can lead to significant changes in how information about a system is spread and is understood by different stakeholders. These ST skills can be accompanied by the use of visual and graphical tools that can help conceptualize the system at hand (*e.g.*, causal-loop diagrams, systems-oriented concept map extension diagrams, stock and flow models, behaviour over time graphs).[40,41]

Research has also shown the importance of using ST skills to examine global challenges. A recent literature review examined research on COVID-19 and its effects on environmental phenomena from a systems-oriented perspective.[24] Selin claims one reason why research on global challenges (*e.g.*, COVID-19) benefits from a ST approach is that "analyses that do not account for systems behaviour risk mischaracterizing the pandemic's impacts, implications, and related causal mechanisms".[24] The review found few studies and commentaries focusing on evaluating environmental and sustainability impacts of COVID-19 using a systems lens.[24] Without a systems lens, scientific journals present the effects of COVID-19 and associated environmental policies separately from its impacts on people and institutions.[24] Information on COVID-19 presented in this way has led to people making arguments that COVID-19 has been beneficial for our Earth based on a few selected factors, and some have made claims that restoring the global environment from the effects of anthropogenic activities is possible through temporary shutdowns.[24] Applying ST skills such as identifying system components and relationships, as well as multiple viewpoints and factors to examine global challenges (*e.g.*, COVID-19 pandemic) could help to avoid these types of mischaracterizations.

Examples of classroom systems thinking activities

Science educators have an important role in equipping the next generations of students and citizens with the skills to deal with false information and learn how to evaluate it using evidence-based approaches. ST has been previously identified as one potential approach that can be used as a tool for modelling misinformation.[42,43] However, this perspective proposes that science students will actively use ST skills to evaluate false information related to global challenges. ST would expand searching for other sources on the same topic by looking at additional factors that could help explain a scientific phenomenon; for example, a lateral reading fact-checker strategy[44] could be used to look at societal, environmental, and political factors. We provide a few examples of ways to use ST to address false information.

Example 1: Use misinformation on a global challenge related to a UN Sustainable Development Goal to introduce a science lesson. The educator could share two media claims, one accurate and one inaccurate, and prompt students through a set of ST questions to identify the accurate scientific information. For example, during a unit on polymers, students could analyze a claim stating that "biodegradable plastics completely solve ocean plastic pollution" alongside a contrasting claim indicating that many biodegradable polymers degrade under specific conditions. Students would use the scientific knowledge learned from the polymer chemistry unit (*e.g.*, polymerization, hydrolysis reactions) and explore additional factors (*e.g.*, temperature, pH, degradation processes, waste-management infrastructure, ocean environments) related to impacts of the global issue (*i.e.*, plastic pollution). Furthermore, students could examine the interactions among chemical, environmental, and human systems, and consider unintended consequences (*e.g.*, leaching of toxic chemicals from plastic

Table 1 A proposed approach of using systems thinking skills to evaluate misinformation on a global challenge (*e.g.*, food security). The left column provides specific systems thinking skills that could be used to evaluate misinformation related to GMOs, and the right column provides an example of how those skills can be implemented in a classroom setting

Systems thinking skill	Example of systems thinking skills in practice
Identify the system of interest and establish its boundaries	• As a class, investigate a global challenge that has been communicated with misinformation and identify what aspect(s) of the challenge to narrow in on. For example, a global challenge of focus could be food security and boundaries could be specifically set around GMOs. The remaining skills will consider GMOs as the system of interest
Identifying system components and their relationships	• Scaffold students in identifying key components and relationships of the GMOs by considering its life cycle (*e.g.*, scientific concepts and processes involved such as, how it is: manufactured, transported, used, disposed of/recycled)
Identify multiple viewpoints/factors	• Scaffold students in examining how different stakeholders/contexts such as economic, societal, environmental, scientific, political factors influence information about GMOs (*e.g.*, media and advocacy groups influence how consumers and policymakers perceive the risks or benefits of GMOs, farmers' adoption of GMO seeds depends on market incentives, access to technology, and trade regulations, research findings inform policy decisions and regulatory frameworks)
Identify feedback loops	• Guide students in identifying reinforcing and balancing feedback loops within the GMO system, to help them identify the sources where misinformation is amplified in the media and what factors support accurate information. (*e.g.*, public mistrust fueled by misinformation about GMOs can pressure governments to impose restrictions, which impacts scientific communication and innovation efforts)
Identify leverage points	• Initiate a reflective discussion on potential actions that could shift the system behaviour, mediating the impacts of the reinforcing feedback loops (*e.g.*, promoting community science engagement to build trust, agricultural literacy in classroom, building science-government relationships to inform policy) • Since previous research has found that sharing perspectives is beneficial for students, the ST activity could end with the students sharing their conclusions and processes (*e.g.*, system maps) to get a collaborative understanding how false information can be evaluated using ST[39]

decomposition, significant amounts of land and water use).[45] Identifying these components and their relationships could help students understand the impact of plastic pollution more holistically and use reasoning skills to determine the accurate claim. Research on ST in chemistry education has found that students engage in multiple levels of reasoning about complex chemical phenomena when using a ST approach, suggesting its potential for supporting the evaluation of inaccurate scientific information.[28,37,46]

Example 2: Have students investigate how misinformation about a global challenge spreads through social, environmental, political, and scientific systems and affects public understanding and action (*e.g.*, climate change). Students could be informed that accurate and inaccurate claims about a global challenge exist and be challenged to identify where these claims originate and their effects on society. Students could work in small groups to map the system of interest surrounding the spread of information about a particular global challenge using visual tools (*e.g.*, creating systems-oriented concept map extension diagrams, also known as system maps, using the SOCKit tool[47]). Using information from news sources, social networks, policy, and scientific literature, the students could be prompted to identify the key components of the system and its interconnections. Using dynamic tools (*e.g.*, Loopy),[48,49] the student could then identify feedback loops that influence social perceptions of the global challenge, distinguishing reinforcing feedback loops that amplify misinformation and balancing feedback loops that counter the misinformation. After constructing their diagrams, students could discuss potential leverage points – strategic places in the system where interventions could reduce the misinformation about the global challenge toward a more accurate and evidence-based understanding.

Example 3: Evaluate genetically modified crops and foods (GMOs) using a ST approach. Table 1 provides an outline of how proposed ST skills could be implemented in a classroom activity, focusing specifically on food security as the global challenge. GMOs represent an aspect of food security that is often surrounded by conflicting messages regarding their impact on human health and the environment, making this topic well-suited for ST evaluation.[50]

Future directions of ST research

Considering how ST is currently being used and investigated in science education, no studies to date have looked at the impact of a ST approach for evaluating inaccurate information in a STEM educational setting. Some questions emerge for science education;

(1) How can a systems thinking approach be used to help students evaluate inaccurate science information?, (2) To what extent can a systems thinking approach help students evaluate inaccurate science information?, (3) What systems thinking skills do students need to develop to evaluate inaccurate science information?, (4) What are the benefits and drawbacks of a systems thinking approach for evaluating inaccurate science information? and (5) What other strategies in tandem with using a systems thinking approach are required for helping students evaluate inaccurate science information, if at all? Based on educators' perspectives of ST approaches, some educators might argue that there is not enough room in the current curriculum, time to implement such an approach or that a ST approach would extend students' cognitive capacity.[51] However, since an example of false information will be closely tied to a context relevant to a course learning outcome, we believe that implementing ST for evaluating false information would closely complement existing approaches, helping mitigate these challenges. While time, space, and cognitive abilities are potential concerns and challenges, empirical investigation is required before making claims on the impact of using ST to evaluate false information.

Development of a more explicit conceptual framework could help guide future work in this area by linking defined systems thinking skills (*e.g.*, establishing boundaries, identifying leverage points) to concrete mechanisms of claim evaluation and to measurable learning outcomes. For example, two existing frameworks could be used to facilitate these connections: (1) epistemic vigilance and (2) scientific argumentation. Epistemic vigilance refers to one's ability to be critically aware of the validity of information to protect against misleading information.[52] Sperber *et al.* (2010) define aspects of epistemic vigilance to consist of being critically aware of the validity of claims and the quality and trustworthiness of the source.[53] Strategies aimed at supporting students' scrutiny of claims and validity include reassessing plausibility[54,55] and engaging in the critique of claims.[56,57] Methods to enhance students' awareness of source quality include reliance on experts[58–60] and evaluating the source of the claims.[61–67] Scientific argumentation is an analytic framework that can be used to evaluate systems thinking skills and aligns well with the aspects of epistemic vigilance. Arguments have the goal of using evidence to persuade and justify a claim and using data and reasoning to advance that claim.[68–71] Since a claim is in doubt, constructing an argument about the relation between known data and an explanation will advance the claim.[68,69] Arguments also provide insight into how students reason about phenomena.[72–75] The modes of reasoning dimension of this framework has been commonly used to evaluate students' arguments about chemical phenomena in chemistry education,[72,76–78] and has been previously used to evaluate chemistry students' systems thinking skills.[28]

Science education research on ST could also draw on existing analytical approaches for assessing global challenges that have been used in scientific research, such as the human-technical-environmental (HTE) systems framework.[79] This framework brings together analysts from different disciplinary backgrounds to study a common way to advance systems-focused research on sustainability issues. Engaging in the HTE systems framework involves identifying and examining the components, considering the interactions among the components, and providing information that can inform interventions.[24] Other scholars have created a framework for conceptualizing science literacy over three dimensions that span the lifecycle of science information.[22] These dimensions include, (1) civic science literacy skills (*e.g.*, understanding how science in produced and how science relates to broader society), (2) digital media science literacy skills (*e.g.*, understanding how science information appears and moves through media systems), and (2) cognitive science literacy skills (*e.g.*, understanding how people interpret science information when they come across it).[22] A ST lens could complement these three dimensions for identifying and evaluating false information.

Limitations

While systems thinking offers promise for supporting misinformation evaluation, it also presents potential limitations and risks that warrant careful consideration in future implementation and research. For novice learners, a systems thinking approach may increase their cognitive load, particularly if multiple systems thinking skills are introduced simultaneously without sufficient scaffolding. In addition, system representations of misinformation may be strategically manipulated through selective boundary setting or variables without considering the full picture. There is also a risk that students and educators adopt a mindset where they think everything is complex and thus disengage from evaluating misinformation. We propose that systems thinking is most likely to support misinformation evaluation when it is explicitly scaffolded, anchored to disciplinary curriculum, and paired with learning outcomes and goals, and may be less effective when learners and educators do not have foundational chemistry and systems thinking knowledge, or when the systems boundaries are ill-defined.

Conclusions

New directions in science education research are needed to investigate systems thinking's role in evaluating false information. There is ample opportunity for exploring science literacy skills, given the prevalence of misinformation and the use of GenAI in the world. Considering the range of complex global challenges we face in society today, there is an urgent need to help citizens and scientists develop the skills required to navigate through our modern, digital world. By equipping citizens and scientists with the necessary skills, they will be more prepared to compete for future jobs and better equipped to advise policymakers who shape the direction of governments and institutions globally.

Author contributions

A. R. S., P. G. M., and A. B. F. conceived the ideas presented in this manuscript. A. R. S. wrote the first draft of manuscript, and all authors edited and revised the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

Data availability

No primary research results, software or code have been included, and no new data were generated or analyzed as part of this article.

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