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Could recent advances and new perspectives in science education and conceptual change improve public understanding of science?

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This perspective article explores the intersection of science education advancements and public science understanding improvement efforts, critiquing the still prevalent "deficit model" of science communication. It argues for a nuanced approach, incorporating insights from conceptual change research and the coexistence of scientific and misconceived notions within learners. Highlighting the prospects and promises of representational pluralism, it suggests strategies for science communicators to foster public engagement, emphasizing the importance of young audiences, avoiding simplistic dichotomies, and promoting critical thinking. The piece advocates for mutual enrichment between science education and communication, aiming for a well-informed, epistemologically competent public capable of navigating the complexities of scientific discourse.

KEYWORDS

public understanding of science, fact-checking, science education, conceptual change, cognitive conflict, representational pluralism

1 Introduction

Ten years ago, Sinatra et al. (2014) suggested that insights from research in epistemic cognition, motivated reasoning, and conceptual change could help address the challenges of improving public science literacy efforts. Unfortunately, this invitation has been largely ignored. Indeed, when science education specialists review the literature describing the current state and evolution of public science communication initiatives, and the recommendations that emanate from them, it seems clear that, apart from a few isolated dialogic initiatives, the "deficit model" still largely prevails and that communicative solutions are generally put forward. The "deficit model" of science communication, and especially of "fact-checking," assumes that public resistance, skepticism or even hostility toward science and technology is primarily due to a lack of knowledge or understanding about science. According to this model, the solution to improving public attitudes toward science is essentially to fill the knowledge gap by providing more scientific information and by doing so effectively. Also known as the Scientific Content [SC] approach, it is still considered dominant today (Keren, 2018). And even though it has been severely criticized (Miller, 2001), and that new forms have been identified through bibliometric analyses (moving from *knowledge* deficit [1960s]; to positive *attitude* deficit [1980s]; to *confidence* deficit [1990s] and finally to *engagement* deficit [2010s]), the idea of bridging a knowledge gap between professional scientific activity and the public never really disappeared. In most evidence-based recommendations, we still find that effective, error-free and efficient communicative strategies (considered as "visually attractive" (Zhu et al., 2021) and even "hyped" (Soto-Sanfiel et al., 2023)) as well as clear and "fact-based" refutations are considered central, even if they have been criticized for being too epistemologically simplistic (Uscinski and Butler, 2013) and for producing at best mixed results (Walter et al., 2020).

It is true however that science teachers and science communicators do not operate under similar constraints. Communicators do not have their audiences at their mercy, as teachers do. The levers associated to school's demand for success (achievement) are not at their disposal. They fall prey to zapping, and indeed, are often zapped. Science teachers and science communicators neither pursue the same exact goals. In most countries today, educational systems aim to develop students' scientific culture and competencies, to raise citizens, responsible consumers, voters, problem solvers and possibly, for a few, scientists, whereas it has been argued that science communication can at best "cultivate 'competent outsiders'" (Keren, 2018, p. 782) with respect to science.

But we believe there is enough convergence to argue for mutual enrichment. After all, science education research has been dealing with misconceptions since at least the 1970s (Disessa, 2006). Such conceptions are clearly assimilable to the concept of misinformation used in science communication. Thus the idea of conceptual change as a field of research and its long and fruitful tradition (Duit and Treagust, 2003) could most likely suggest insights. It has also yielded rather convincing positive results, not only for typical misconceptions (*force causes movement*; *clouds are made of vapor water*, and so on) but also for misconceptions that address larger, typical of science communication issues, such as climate change (Lombardi et al., 2013; Ranney and Clark, 2016). Thus, we argue that Sinatra et al.'s invitation should remain active, and we propose to update it considering a set of selected and latest results as well as original perspectives in the field. We hope that our perspective may inform scientific communicators of all types (researchers, managers, communication specialists who may come from agencies, non-profit organisations, academia or industry, etc.) pursuing the objective of improving the scope and effectiveness of their action, and sensitive to the potential of interdisciplinary contributions. Recent results and new perspectives in science education.

1.1 Response of learners to conflicting information

A comprehensive review published in 2023 has shed light on the reasons why students sometimes reject or accept ideas that conflict with their previous ones. This systematic study reviewed 86 peer-reviewed articles that were published in science education journals, selected in order to promote a better understanding of conceptual conflict events. It aimed at documenting the preliminary conditions, the process and the outcomes of cognitive-conflict events. The studies cited here mostly used questionnaires and in-depth interviews, to ask learners about the intimate *reasons* why they adhere or do not adhere to discrepant ideas or conflicting information. The results show an impressive list—in terms of length—of 11 distinct and possible outcomes of cognitive conflicts: (1) *Subassimilation*: A response where learners attempt to assimilate the new information but do so in a fragmented or incomplete manner, falling short of full understanding, and thus being unable to even detect contradictions; (2) *Ignoring*: Overlooking the anomalous data as if it wasn't presented; (3) *Rejection*: Outright refusal to accept the anomalous data because it conflicts with existing beliefs; (4) *Exclusion*: Acknowledging the data but considering it an outlier that does not affect the general understanding; (5) *Uncertainty about Validity*: Doubting the truthfulness, source, or reliability of the anomalous data; (6) *Uncertainty about Interpretation*: Being uncertain about how to interpret the anomalous data, even though its validity is not questioned; (7) *Abeyance*: Temporarily suspending judgment about the anomalous data, neither accepting nor rejecting it; (8) *Reinterpretation*: Modifying the interpretation of the data to fit existing beliefs; (9) *Belief Decrease*: Reduction in the confidence of the initial belief but without a shift to a new understanding; (10) *Peripheral Change*: Making minor adjustments to the existing belief system to accommodate the new data without fundamental conceptual change; (11) *Theory Change* or *Belief Change*: Undergoing a fundamental shift in understanding or beliefs to accommodate the new data, representing genuine conceptual change.

Surprisingly, depending on the studies analyzed, the review (Potvin, 2023) found that the distribution of responses from one category to the other was rather evenly distributed, indicating that the desired category (theory or belief change) was largely minority, and that the obstacles to the consideration on new and initially uncomfortable ideas are many. The review also suggests that resolving cognitive conflict requires additional processing activities, such as discussion or structured reflection, that can help learners integrate new information effectively, and thus that cognitive conflict alone clearly appears insufficient. Finally, it identifies several factors that influence the effectiveness of presenting contradicting information to learners. These include rather trivial things such as learner's cognitive abilities, epistemological beliefs, affective and attitudinal states, initial confidence in their preconceptions, but also other interesting things like the initial availability of a conceptual "plan B" (p. 84). The review insists on this finding. Conceptual change seems to require that one already has a conceptual backup plan if he/she is to be productively contradicted.

1.2 Coexistence of conceptions

In recent years, a growing body of research has shown that modifying or discarding initial conceptions might not be a necessity, nor likely, in the process of conceptual learning in science. This insight has emerged from studies using mental chronometry methods (Babai et al., 2010; Brault Foisy et al., 2021; Lin et al., 2023; Potvin et al., 2015; Shtulman and Valcarcel, 2012; Wen et al., 2024), neuroimaging (Brault Foisy et al., 2015; Masson et al., 2014), and electroencephalography (Skelling-Desmeules et al., 2021; Zhu et al., 2019) showing that even when correct responses are given, underlying misconceptions can still influence thought processes, even in experts (Allaire-Duquette et al., 2021; Potvin et al., 2020). Such findings suggest that learning new concepts does not eliminate old ones, and that new conceptions, when learning is successful, new concepts coexists with pre-existing ones, requiring the inhibition of the latter for expertise development. This notion of coexistence challenges traditional views in science education and urges a reevaluation of pedagogical approaches to incorporate the understanding that multiple conceptions can persist simultaneously within a single learner. It suggests that a conceptual change event should be understood as a conceptual prevalence shift rather that a rejection or a transformation.

Among the recommendations that have emerged from this observation (Potvin, 2017), it is suggested that we simply stop waging explicit wars on misconceptions. It argues against systematically discrediting misconceptions, suggesting instead that expertise requires the ability to inhibit rather than to eliminate them. It also recommends the use of different sequencings in teaching efforts and suggests that for students without an already available rival theory to the scientific models being taught, direct confrontation with anomalies may not lead to the desired learning outcome. An alternative might be to first introduce the desired scientific model that can then facilitate productive "theory-theory" conflicts. In this perspective, cognitive conflicts should be resolved based on the systematic and explicit evaluation of cognitive utilities of competing models rather than solely on their scientific accuracy (or inaccuracy). This could also prevent some negative impacts on students' self-concept and interest in science, since learners often believe that discrediting an idea discredits its bearer.

In this "coexistence" perspective, it also appears crucial to reflect on the durability of prevalences. To achieve lasting expertise, educational programs and well-designed sequences may be required, not mere punctual interventions (Potvin, 2017). Indeed, apparent reversions to initial conceptions are common. So strategies that secure the durability of the prevalence of desired conceptions should be favored. It also suggests that starting science education early in life and with a focus on didactical quality could prevent the eventual and precocious establishment of undesirable conceptions, therefore avoiding the later necessity to undergo costly changes.

1.3 Representational pluralism

The constructs of coexistence and prevalence naturally lead to a representational-pluralist perspective that is even broader and more encompassing than mere conceptual prevalence framework. It also opens more educational opportunities. Representational pluralism, as it has recently been suggested and developed (Bélanger and Potvin, 2022; Bélanger et al., 2022), is based on an explicit rejection of an ideal of human knowledge consisting in the possession of a "single best" representation of a phenomenon. For instance, the intuitive idea that rolling soccer balls stop by themselves after being kicked is "true enough" in a sport context, although the Newtonian account of what happens will be expected in a school context. Cognitively speaking, such intuition does sufficiently proper job in its context of use. Generally, a pluralist perspective posits that individuals naturally tend to develop or preserve multiple representations of a given phenomenon (Horst, 2016). And this happens at any level of expertise. Just like students can keep useful intuitions despite having developed some level of understanding and belief of scientific representations, scientists often develop various theories and models that enable people to think about phenomena and act on them efficiently according to their various purposes.

One useful analogy for thinking about pluralism compares representations to tools (Bélanger and Richard, 2024). Tools are artifacts created by humans to help us achieve certain goals. No tool is said to be 'truer' than another; a tool can only be said to produce better performances than another for such and such a purpose. For instance, in some circumstances an impact driver is more useful than a screwdriver but not in others. Likewise, representations can be thought of as intellectual technologies, intentionally developed for a purpose, with a value relative to this purpose. In this pluralist perspective of cognition, science learning is to be seen as the acquisition of powerful representations offering new capabilities for thinking and acting in the world. But just like we do not throw away our screwdrivers after having bought an impact driver, we should not be expected to stop using intuitive representations. Conceptual change research has univocally taught us that intuitive representations are quite persistent; the pluralist perspective wishes to stress that part of this is due to their cognitive usefulness (Ohlsson, 2013). Although, as scientists, we may be despondent about the level of scientific falsehood of these intuitions and would find it quite convenient that they give way during learning, the fact is that many of them might be there to stay. Pluralism put forwards the idea that this cohabitation is not only inevitable, but normal and even something positive.

From such pluralist perspective, students' intuitive ideas and scientific concepts can both have value in different contexts. Successful learning then implies not just the acquisition of scientific concepts but also the development of the ability to navigate between different representations and to apply them appropriately in various contexts. This is precisely what you are expected to do with a toolbox. Accordingly, teaching strategies should recognize and engage with the diversity of representations and develop ways to navigate and utilize this diversity effectively (Bélanger and Richard, 2024). For instance, the "conceptual prevalence" model suggests teaching strategies that do not aim to eliminate students' intuitive representations but instead focus on developing strategies for when and how to prioritize scientific concepts over intuitive ones. It is important to emphasize here that the pluralism we are talking about does not call for the endorsement of false ideas that should be considered as equally valid as, or equivalent to, scientific knowledge. The project of successful science communication is not a relativistic project.

But taking pluralism seriously can bring us further in rethinking what we consider cognitive expertise about a domain to be. Pluralism insists on the fact that the truth of scientific representations is not all there is for human cognition: practically useful intuitive representations also have cognitive value. But just as the cognitive interests of humans are not limited to true representations, they are not limited to practical usefulness neither. Sometimes, we have interest in what is merely possible, because what is only possible today might reveals itself to be a truth tomorrow. Humans often have to deal with states of incomplete knowledge, and if they are to cognitively go forward nevertheless, they must do so in terms of the *possibility* of various competitive representations.

A strong pluralist view can go even further and acknowledge that there is some cognitive interest in what is judged entirely false and practically useless. Sometimes, it is a good thing to have some understanding of what other people think, even if we reject it. The cognitive value of such representations is social in nature. Giving students access to scientific knowledge is eminently desirable but enabling them to have empathic and fruitful interactions with people holding different views is also part of educating them to be citizen within an increasingly complex society.

Ultimately, a representational pluralist perspective on science education stresses that the learning of science consists not only in the understand scientific theories and models, but also in their effective use, as well as in the development of epistemological competency, critical thinking skills and empathic capabilities. Above all, it stresses the importance of treating representations (scientific and intuitive alike) as *objects* constructed by humans, whose properties (truth, usefulness, simplicity, *understability*, etc.) can be discussed and deliberatively weighed by students (Bélanger and Richard, 2024).

2 Discussion

The interface between science education and public understanding of science is a fertile ground for cross-pollination of ideas and strategies. In an era characterized by a deluge of information and the pervasive challenge of misinformation, it is more crucial than ever to employ evidence-based approaches to science communication. Drawing from the rich insights of science education research, this discussion outlines strategies to enhance public engagement with science, emphasizing the importance of understanding learners' responses, the strategic targeting of young audiences, and the nuanced presentation of scientific information.

2.1 Understanding learners' responses to conflicting information

A pivotal aspect of bridging science education insights with public science communication efforts may lie in comprehending how individuals respond to conflicting information. Research in science education has highlighted a spectrum of responses, from outright rejection to the acceptance of new ideas, underscoring the complexity and difficulty of conceptual change. By anticipating the public's reactions to scientific information that contradicts their pre-existing beliefs, science communicators can tailor their messages to mitigate resistance and foster open-minded engagement. Implementing structured reflection and discussion, as suggested -specifically for example, in socioeducational settings, could facilitate the integration of new information, making the public more receptive to scientific messages.

2.2 Focusing on youth as a strategic audience

Given the difficulty associated with achieving conceptual change, especially in adults, science communication efforts may yield more significant impact by focusing on younger audiences. Early education presents an opportune window for shaping scientific understanding and attitudes, potentially circumventing the entrenched misconceptions that are harder to address in later life. This strategic focus does not diminish the importance of engaging adult audiences but highlights a complementary pathway to bolstering the public's scientific literacy over the long term.

2.3 Sequencing of messages and providing conceptual alternatives

The sequencing of scientific messages and the provision of "conceptual Plan Bs" are critical for enhancing the acceptance of scientific arguments and the effectiveness of rebuttals, like in fact-checking efforts. Science communication initiatives could benefit from first introducing audiences to alternative scientific concepts that allow for a shift in understanding without triggering sterile defensiveness or principled resistance. And then begin discussion about the respective value of possibly conflicting ideas. This approach requires a nuanced understanding of different publics and the tailoring of messages to meet their specific needs and initial levels of understanding.

2.4 Avoiding simplistic true/false dichotomies

The complex nature of scientific knowledge demands a communication strategy that transcends simple true/false dichotomies, which can foster a dogmatic view of science. Instead, presenting scientific controversies as evolving narratives that welcome multiple perspectives encourages a more sophisticated engagement with scientific content. This approach not only respects the intelligence of the public but also nurtures critical thinking and a deeper appreciation for the provisional nature of scientific knowledge.

2.5 Valuing pluralistic approaches and rival/possible theories

Embracing a pluralistic approach to science communication, which acknowledges the coexistence of multiple, often conflicting, representations of scientific phenomena, can enrich public engagement with science. By presenting rival theories (and the contexts in which they may hold validity), as well as more prospective possible theories (with a discussion of their level of plausibility), communicators can foster a more nuanced understanding of science as a dynamic and evolving field. This approach also highlights the value of scientific debate and the exploration of different theoretical perspectives.

2.6 Encouraging the development of critical thinking and cognitive empathy

In the face of pervasive misinformation, it is tempting to adopt a defensive stance aimed at correcting misconceptions. However, a more effective strategy may be to equip the public with the tools, like epistemic concepts and criteria, to critically discuss and evaluate the relative merits of partially or completely contradictory scientific conceptions, in light of facts. This approach fosters an environment where critical thinking and epistemological reflection are valued over the mere acceptance of information as indisputable fact. This suggestion should however be carried out with competence, if we do not want constructive skepticism to turn into dry mistrust toward partial states of knowledge necessarily omnipresent in scientific research. And looking in the other direction, critical powers backed by scientific knowledge should be used respectfully in discussions with people holding what can be considered naïve of false representations. Preserving the social fabric requires some level of empathy.

We conclude this commentary by reiterating that we believe that insights from science education research could provide an interesting framework for improving public understanding of science, although obviously not everything can be imported, as there are important operational differences. But by adopting strategies that acknowledge the complexity of learning and conceptual shifts (rather than "change"), it is not unreasonable to think that science communication initiatives could engage audiences more effectively and foster a well-informed, more epistemologically competent, and critically thinking public. As we continue to face the challenges of misinformation and mistrust, the mutual exchange of knowledge between science educators and communicators becomes increasingly important. We invite experts in public communication to share their insights in the hope of enriching the dialogue between our fields and collectively advancing public and student engagement with authentic scientific activities and outcomes.

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 author.

Author contributions

PP: Writing – original draft. MB: Conceptualization, Writing – review & editing.

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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.

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