ECLÉTICA QUÍMICA

Eclet. Quim. 50 | e-1530, 2025

Review Article, Celebrating the centenary of the 20th century Acid-Base Theory

https://doi.org/10.26850/1678-4618.eq.v50.2025.e1530

Teaching acid-base theories in the era of disinformation: A systematic review with proposals for content integration

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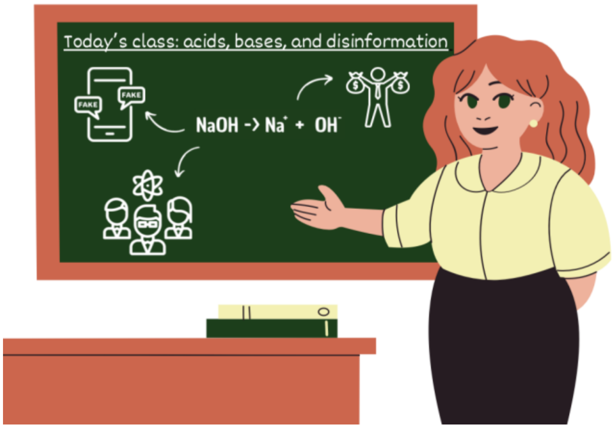
Abstract

This paper is rooted in the premise that addressing scientific disinformation and misinformation about acid-base theories requires a multidisciplinary approach, approximating acid-base knowledge with content typically not addressed in chemistry classes. Stemming from this principle, this paper analyzes how peer-reviewed publications for chemistry teaching approach the representation of acid-base theories in the context of informational disorders (disinformation and misinformation) through a literature review and textual analysis. The papers analyzed address cases of informational disorders through a disciplinary lens, with a pronounced emphasis on resorting to acid-base contents to debunk erroneous messages, even though the contexts explored reference socioscientific issues. As a response, this paper broadens the conservation, by proposing other contents that could convey the nature of science as well, the functioning of traditional and modern media, and values and ideologies. By doing so, this paper provides more elements for critical and broader readings of acid-base theories in informational disorders, elevating chemistry teaching to better address contemporary challenges arising from the interplay between science and media.



Article History

Received November 16, 2023
Accepted January 15, 2025
Published August 13, 2025

Keywords

1. chemistry teaching;
2. critical thinking;
3. fake news;
4. media literacy;
5. science.

Section Editors

Glaucia Maria da Silva **Degrève**
Natany Dayani de Souza **Assai**
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Highlights

- Disinformation on pH and diets calls for new approaches in acid-base teaching.
- A systematic review and thematic analysis guide the study's methodology.
- The review exposes limits of disciplinary acid-base teaching.
- Media, and communication studies enrich acid-base teaching in this paper.

CONTENTS

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1. Introduction

The 100th anniversary of acid-base theories offers an opportunity to reflect on how that knowledge is represented beyond textbooks and Chemistry classes, and how educators might enhance their effectiveness in teaching those theories in more coherent, relevant and transformative manners. Over a century of academic knowledge production on acids and bases, alongside the "scholarization" of acid-base theories, has revealed numerous challenges in teaching this topic. These challenges include a lack of conceptual and classificatory accuracy in textbooks (e.g. Campos and Silva, 1999; Lima and Moradillo, 2019), an insufficient or deficient approach regarding the phenomenological and particle levels during instructional processes (e.g. Drechsler and Van Direl, 2007; Furió-Más *et al.*, 2005), and a limited alignment of epistemological and historical approaches with core concepts (e.g. Souza and Silva, 2018). Indeed, teaching acids and bases highlights a central issue in chemistry education: establishing effective and meaningful connections between the macroscopic, microscopic, and symbolic levels and other domains, such as science, technology, and society (STS), history of science, and epistemology.

This paper addresses some of those challenges, especially regarding the portrayal of acids and bases in the media. Paying attention to this specific context is deemed relevant in current times marked by social media and an influential load of inaccurate scientific information.

To provide a glance at the inaccuracies, a message highly shared on WhatsApp during the pandemic offered a misleading treatment for COVID-19 based on an alkaline diet, alleging that SARS-CoV-2 possesses an acidic nature (Locatelli, 2021). The message recommended consuming lemon (with a supposed pH of 9.9) and avocado (with an alleged pH of 15.6). In another case of WhatsApp's content, a post falsely attributed to specialists from the clinical hospital of São Paulo, Brazil, erroneously compared the alkaline property of herbal teas to the efficiency of antiviral drugs as an alternative way to treat the flu (Ghinea *et al.*, 2020). Claims like the previous ones concerning health have particularly severe consequences regarding people's quality of life (Swire-Thompson and Lazer, 2022).

Considering messages that contest core scientific principles, it is crucial to confront them through the lens of misinformation and disinformation, terms that are part of the wider concept of information disorders (UNESCO, 2019). According to Swire-Thompson and Lazer (2022), misinformation is information contrary to the current scientific consensus; disinformation has the added attribute of being spread deliberately to gain money, power, or reputation. Both are problems for society, but disinformation is particularly dangerous because it is frequently organized, well-resourced, and reinforced by automated technology (UNESCO, 2019).

In the new scenario of social media, where the production and spread of scientific disinformation have reached unprecedented levels, it is reasonable to redouble efforts at teaching critical thinking, integrating critical discussion about media and science, aiming for civic and critical thinking training for everyone (Arroio, 2017). It would not be different for chemistry teaching, mainly when socioscientific problems (such as the COVID-19 pandemic) are intertwined with media, information, power, along with knowledge about science practices and contents (Siqueira and Arroio, 2022).

1.1. Teaching science in times of digital media and disinformation

In today's global communication ecosystem, scientific knowledge, reliable information, and even facts often wield less influence than emotional appeals and personal opinions in shaping individual and collective decisions (Arroio, 2017). This is particularly evident in matters such as vaccination, elections, and climate crisis policymaking (Feinstein and Waddington, 2020). Some even name this historical moment the post-truth era, denoting "circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief" (Oxford Languages, 2016). Valladares (2022) points out two factors that might explain post-truth: (1) socio-technical advancements of digital societies, which enable the rapid spread of vast amounts of information on social media; (2) and individuals with political agendas and corporate economic interests who further distort information to serve partisan goals or profit-driven projects. Notably, digital media plays a pivotal role in both factors.

In this scenario, a compelling argument for science educators is that they should go beyond teaching traditional scientific knowledge in the form of concepts and theories. Osborne and Pimentel (2023) argue that nowadays it is essential to prepare students as "competent outsiders" –individuals who can critically evaluate scientific claims and determine the credibility of sources– rather than "competent insiders", who possess a broad but surface-level understanding of scientific concepts gained through formal education. To interact critically with scientific information, Höttecke and Allchin (2020) argue that students need a holistic understanding of the epistemic structure and provenance of scientific claims encountered in everyday life. This involves understanding the nature of science communication, including the full trajectory of these claims – the mechanisms, mediations, and potential distortions – as they move from experts to the public sphere through digital media (Allchin, 2021; Miller *et al.,* 2021; Reid and Norris, 2015). In summary, this approach highlights the urgency of examining the pathways through which knowledge is mediated –from "test tubes to YouTube" and from "lab book to Facebook" (Höttecke and Allchin, 2020, p. 644)– to assess how knowledge maintains its integrity and reliability and to explore the social architecture that sustains and justifies trust in science.

In the context of disinformation and the digital media landscape, science educators must recognize the enduring importance of teaching scientific concepts and theories. Valladares (2021) highlights that a crucial yet often-overlooked dimension of contemporary science literacy is the ability to read and write using the specific codes, norms, and language of science. Science educators bear a historical and cultural responsibility to equip students with the skills needed to effectively engage in scientific language. Because scientific practices are inherently textual, proficiency in reading, writing, and communicating scientific information is essential for a deeper understanding of science itself (Santos, 2007; Silva and Sasseron, 2021; Valladares, 2021). Furthermore, it is well understood that this fundamental aspect of scientific literacy, when integrated with suitable educational goals, approaches, and other knowledge, offers essential and transformative potential in an era dominated by digital media and disinformation (Siqueira and Arroio, 2022). After all, concepts like pH and acid-base theories are key to unveiling disinformation, such as that surrounding so-called alkaline diets.

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In summary, a prominent approach to teaching science in the current era is to foster the ability to read and write in the language of science, promote an understanding of the nature of science communication –including its norms, social actors, and epistemological practices– and integrate critical, technical knowledge of media and digital communication, such as its languages, values, interests, and ideologies (Belova and Eilks, 2015; Cardoso and Gurgel, 2019; Silva and Arroio, 2025; Siqueira and Arroio, 2022).

This paper examines how peer-reviewed publications for chemistry teaching approach the representation of acid-base theories in the context of informational disorders, and expands, when appropriate, their contributions by proposing additional content that could be integrated into chemistry classes alongside the analyzed cases. Ultimately, it is expected to provide more elements for critical and broader readings of acid-base theories in traditional and modern media, particularly in the context of disinformation and misinformation.

2. Experimental

The experimental approach begins with a systematic review (Aromataris and Pearson, 2014; Shaheen *et al.*, 2023) to select peer-reviewed papers in both English and Portuguese that examine the representation of acid and base content within information disorders across various media genres. Furthermore, this analysis specifically focuses on publications of Chemistry teaching. As a following step, the experimental procedure also included reanalyzing, when necessary, some of the media and messages conveyed in the papers through a critical lens, suggesting other contents that could be addressed in chemistry classes. In this sense, the experimental procedure consists of four procedures as follows.

2.1. Procedure 1

Through a systematic review, the first step included consulting six academic databases (ERIC, Scielo, Latina, Scopus, Web of Science, and CAPES journals) whose indexed papers contained in the title, summary, or keywords the following terms: fake news AND chemistry; disinformation AND chemistry; misinformation AND chemistry; conspiracy theory AND chemistry; post-truth AND chemistry[1]. The keywords were systematically selected to capture meanings related to informational disorders, aligning with Shaheen *et al.* (2023)'s recommendations on identifying key concepts, search terms, and establishing appropriate inclusion and exclusion criteria. Considering the narrow context of the search, no time constraints were applied. With the search results, this first procedure entailed reading all the resulting papers' titles and summaries to select those related to chemistry teaching. This first curation process resulted in ten peer-reviewed publications.

2.2. Procedure 2

The second step involved reading all ten papers from procedure one, with the aim of selecting those that partially or integrally address acid-base theories. This second curation procedure resulted in four peer-reviewed papers (**Table 1**).

Table 1. Papers that address information disorders related to acid-base theories in media for chemistry teaching.

Papers	Authors	Title	How acid-base-related contents are explored
I	Cunha (2021)	[Chemistry in Fake Science] A Química "mal dita" em *Fake Science*	The paper analyzes fake science messages (according to the authors, fake news with scientific content) in written and video formats spread on WhatsApp during the first two years of the COVID-19 pandemic. The publication aims to provide teachers with classroom material to problematize and discuss chemistry and the nature of science knowledge present in fake science messages. The paper presents and discusses chemistry-related content from seven messages. In five of them, acid and base theories are conveyed.
II	Ribeiro *et al.*, (2022)	[Discussing fake news related to chemistry during the COVID-19 pandemic: what was its influence on students?] Discutindo fake news sobre química durante a pandemia da COVID-19: como elas têm influenciado os alunos?	The paper analyzes and discusses students' responses to twelve affirmations related to cases of disinformation broadly spread online during the first two years of the COVID-19 pandemic. One hundred twenty-two high school students participated in the research. The twelve affirmations are further contextualized and corrected from the perspective of the related chemical concepts. Among the affirmations, three convey acid-base theories: 1) Vinegar is a more efficient alternative to protect against the virus than alcohol gel; 2) Lemon is an alkaline and efficient fruit to protect against the SARS-Cov-2 virus; 3) Gargling with water and baking soda helps to protect against the virus.
III	Toby (1997)	Chemistry in the Public Domain: A Plethora of Misinformation—or Don't Believe Everything You Read in the Newspapers!	The paper presents examples of various kinds of chemical information disorders culled from newspapers and magazines. The media's statements are debated, considering the (in)accuracy of the associated chemical concepts. The paper shows and discusses twelve excerpts, some with conceptual errors and others with quantitative mistakes. Two of them are related to acid-base theories.
IV	Algarra *et al.* (2008)	Magnetized Water: Science or Fraud?	The paper presents the results of a laboratory experiment measuring drinking water's total hardness, surface tension, and pH after filtration through a commercial device. It also problematizes how chemistry concepts are portrayed in the device's advertisement.

Source: Elaborated by the authors.

[1]For each database, a second round of searches was conducted using the equivalent terms in Portuguese: *Fake news* AND *química*; *desinformação* AND *química*; *informação incorreta* AND *química*; *teoria da conspiração* AND *química*; *pós-verdade* AND *química*.

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2.3. Procedure 3

The third step included identifying patterns and trends, resorting to the principles of thematic analyses, a method of qualitative data analysis to identify, analyze, interpret, and report patterns (themes) from qualitative data, such as textual documents (Souza, 2019). Thematic analyses were crucial for identifying trends in how acid-base contents are conveyed in the publications and for highlighting gaps to recommend contents that could be addressed from the media and contexts under study (following procedure).

2.4. Procedure 4

Stemming from the patterns and gaps identified in the previous step, the final phase involved selecting and adapting additional content that could be incorporated into chemistry classes. This selection considered the media and contexts analyzed in the reviewed publications and was grounded in contemporary science education literature, particularly debates surrounding science, media, and informational disorders.

3. Results and discussion

First, it is essential to highlight that systematic reviews do not require a minimum number of resulting studies, as they can vary significantly depending on the research topic, investigative focus, and available evidence (Aromataris and Pearson, 2014). This paper argues that in the context under study, four papers are insufficient to establish patterns among data, primarily due to the narrow scope of investigation: academic peer review focused on acid-base content within information disorders across various media genres. However, there is value in this limited dataset. As Shaheen *et al.* (2023) point out, in cases where available or reliable data is lacking, it is imperative to explicitly state limitations and provide a sound rationale for the absence or unreliability of data. Shaheen *et al*. (2023) further note that while statistical tests typically require larger sample sizes to ensure representative distributions and enable generalizations, the relevance of sample size in qualitative research is generally reduced. Therefore, despite the limited results, this paper focuses on reinforcing or proposing perspectives for teaching acid-base theories in the context of information disorders, relying on the current review findings without applying quantitative treatments.

The four publications explore acid-base contents through socio-scientific contexts: the COVID-19 pandemic (papers I and II), chemistry-related information disorders in newspapers and magazines (paper III), and water-filtering health claims (paper IV). Through these studies, the authors underscore the crucial role of natural science and chemistry teaching in understanding chemical content in various media (social media, TV, magazines, and newspapers). More importantly, all of them stress the significance of contextual learning in enhancing the relevance of chemistry teaching.

Besides, it is highlighted that knowing chemical contents (papers I, II, III) and processes (paper IV) – in other words, having conceptual and procedural understanding – is a legitimate way to not fall for information disorders in traditional and digital media. As paper IV's authors state, "Chemistry applied to magnetic treatments of water provides a good opportunity to help university and secondary students develop educated skepticism against claims made about some products" (Algarra *et al*., 2008, p. 1416). Paper IV is the only article that goes beyond a conceptual approach, demonstrating how advertisement claims can be verified by experimentation and conceptual discussion, such as pH scale.

The acid-base contents are addressed in various forms and include pH scale (papers I, II, and III), acid-base reactions (paper I and III), and buffer solutions (paper I). The authors use contents to debunk the information disorder, as seen in paper I, which discredits a message claiming that tea with lemon and sodium bicarbonate can alkalize the immune system and cure COVID-19:

> Sodium bicarbonate ($NaHCO_3$), is classified as an acidic salt [....] If it is mixed with any acid, it releases carbon dioxide and water. Its most well-known use is as a stomach antacid, neutralizing the excess HCl present in gastric juice. The mixture of sodium bicarbonate and lemon acts as a buffer in the body, and there is no evidence that it works in viral conditions (Cunha, 2021, p. 9).

It is worth highlighting that the paper I stands out as the only publication concerned with preliminary aspects of media literacy and the nature of science. It suggests that discussions should include: how scientific authority is used to legitimize disinformation; how scientific knowledge is produced; and how social media platforms influence the circulation and reach of false scientific claims. However, in paper I, these elements are only briefly suggested, focusing predominantly on a conceptual analysis aimed at debunking acid-base-related information disorders.

Acknowledging the significance of these conceptual approaches, this paper advocates for expanded discussions on media and messages, considering contemporary challenges and what science education can be in service for nowadays. For example, papers II, III, and IV do not go further and discuss elements both fundamental for media literacy and science literacy, such as: how the messages were created and distributed; how nature of science is portrayed; what values and ideologies are present or absent; how and why the platforms that distribute the messages affect them; etc. In the next section, this paper amplifies the debate, suggesting contents that go beyond the text (or the acid-base contents) and bringing up contents that compose the messages' broader context. Those contents are usually absent in traditional chemistry classes but are recognized as fundamentals to make them more contextual and meaningful in contemporary times.

3.1. Nature of science

One disinformation analyzed by Paper I refers to a video message through which an unidentified person defends a highly efficient COVID-19 treatment assigned by Professor Chen Durrine, an alleged medical researcher in the Military Hospital of Pequin, China. The narrator claims that hot lemon can inhibit the proliferation of the SARS-Cov-2 virus. For this, the lemon must be cut into three parts and mixed with hot water, which would transform the blend into alkaline water. Moreover, the person claims that the carboxylic acids from the lemon tea could yet regulate hypertension, blood circulation, and reduce blood clotting.

Paper I's author debunks the claim of "alkaline water" made of lemon tea, using the chemical concepts of acids and bases, pH scale, and buffer solution. They also briefly commented that there was not enough evidence about the claimed efficiency of vitamin C (ascorbic acid) against COVID-19. Departing from the cited disinformation, those elements are suggested to be addressed in the chemistry classroom, but with more emphasis on the conceptual domain. Taking into consideration the paper's findings about the disinformation mentioned, it is argued that the nature of science is one aspect that can be covered with similar emphasis.

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To better understand how science-related information is conveyed in media, specialists advocate fostering in science classes a deeper understanding of how scientific knowledge is created and communicated (Allchin, 2021; Osborne and Pimentel, 2023; Reid and Norris, 2015). For example, it is not desirable to solely question the existence or non-existence of the cited Military Hospital of Pequin and its researcher, Professor Chen Durrine, but also debate whether one researcher or one research center is enough to represent scientific knowledge. Science is a social enterprise based on the consensus of specialists (Allchin, 2012; Höttecke and Allchin, 2020; Oreskes, 2019). Moreover, understanding scientific knowledge as the result of rigorous consensus among experts from diverse backgrounds and experiences is a crucial factor that makes science more reliable than other forms of knowledge (Valladares, 2022).

It is also necessary to recognize that science requires the contribution of those with relevant background knowledge (Oreskes, 2019). Thus, a statement made in the name of science by someone without expertise in the relevant scientific disciplines—such as a physician promoting an alkaline diet—is practically meaningless if it does not align with and reinforce the consensus established by scientific specialists. Under this approach, the focus is to investigate the author, not the (dis)information content, since science is a social endeavor, and epistemic trust emerges as a critical aspect (Oreskes, 2019). This is evident in the reliance on the work and findings of other specialists, their critiques, and so forth. However, trust is not assumed, but earned based on a track record of credentials, such as quality of educational background, mentors, coauthors, and home institutions (Höttecke and Allchin, 2020; Reid and Norris, 2015; Valladares, 2022). In this sense, Paper II's authors discuss a disinformation video through which a worker of the chemistry industry in Brazil, proclaiming himself as a self-educated chemist, criticizes the use of alcohol 70% (w/v) to combat SARS-Cov-2. According to him, the hygiene protocols with alcohol 70% were recommended solely and exclusively for the financial gain of the pharmaceutical industry, suggesting the use of vinegar for hand sanitation instead. Conceptual and procedural mistakes can be easily pointed out in the self-educated chemist's statement. The attempt to speak on behalf of science, by self-assigning credentials as a chemist, presents an intriguing case for discussing consensus, expertise, and epistemological trust. This is particularly relevant since, despite lacking a formal degree in chemistry, not all chemists may be considered experts in the specific matter addressed.

In summary, consensus, expertise, and epistemological trust are key attributes underpinning science's reliability. As Valladares (2022, p. 1326) states, they "[...] guarantee that personal judgments and opinions [...] do not dominate over the rest and be controlled intersubjectively, to a significant degree, by trained collectives, who have credentials that [...] identify them as experts in a field".

Another essential aspect emerged from the analyzes made by the four papers, but not fully addressed in any of them, is uncertainty. Paper IV's authors, for example, state that the results obtained in the experiment do not support the claims that the water filter's magnetizer acts on water properties as it is amply advertised. However, they acknowledge that only a limited number of experimental measurements for each parameter were made and students should draw their conclusions based on the experimental setting adopted and the resulting outcomes. In the same venue, Paper I's author analyzes a disinformation spread on WhatsApp in which it is promised that a mixture of lemon, baking soda, and hot water would eliminate SARS-Cov-2. To debunk this disinformation, the author starts by declaring that the mixture serves as a buffer solution in the body, and there is no evidence that it acts on viral conditions. Here, stemming from the recognition that additional experiments could strengthen Paper IV's conclusions and the observation that there is no evidence supporting the claim analyzed in Paper I, it is crucial to acknowledge that these nuances of uncertainty –an inherent part of scientific practices– are often met with skepticism or outright denial by those unfamiliar with nature of science (Rosenberg *et al.*, 2022). People usually do not deal with uncertainty without anguish; the assurance offered by some health-related disinformation is appealing and comforting (Lu *et al.*, 2021). Therefore, when dealing with scientific disinformation, it is crucial to address uncertainty as a content to better comprehend science limitations, not ceasing to be a uniquely important tool for addressing socioscientific problems (Covitt and Anderson, 2022). It is plausible to address elements of uncertainty in both quantitative forms (e.g., error bars, ranges of predictions, statistical tests, etc.) and qualitative forms (e.g., alternative hypotheses, limitations of studies, questions for future research, etc.) (Covitt and Anderson, 2022). Yet, teaching about uncertainty in the mentioned context also means complexifying the usual science class exercise of labeling information as fact (scientifically correct) or fake (scientifically incorrect). Care should be taken not to reduce the problem of disinformation to a simple true-or-false dichotomy; instead, students must understand that truth can sometimes be inaccessible, and that knowledge may be uncertain, biased, or ambiguous (Hauge, 2022).

Incorporating subjects and practices related to the nature of science can foster a deeper understanding of how science is conducted and functions as a social institution. Teaching the nature of science in these terms emphasizes epistemological performance as a core competence across the curriculum (Valladares, 2021). Without this focus, science education risks falling short of its transformative potential.

3.2. Traditional and modern media functioning

One crucial dimension to better understand how scientific (dis)information circulates into society is to comprehend how scientific claims reach the lay public. This is a fundamental aspect of the nature of science, precisely regarding how science communication happens in and outside of scientific communities (Belova and Eilks, 2015; Cardoso and Gurgel, 2019; Siqueira and Arroio, 2022). Teaching and learning about science also include a broader epistemological understanding of scientific knowledge flow (Allchin, 2015). Taking this approach, it is highlighted following the role of traditional and modern media in providing access to and transforming scientific information.

Beginning with traditional media, Paper III's author highlights imprecisions about chemical concepts in newspapers, as exemplified by a U.S. newspaper's statement about ammonia's contribution to acid rain (potentially a case of scientific misinformation). This serves as an opportunity to delve into two key contents: mediation and the role of media as gatekeepers. First, this mediation process –or conveying knowledge to lay public– is not a neutral enterprise (Funk *et al.*, 2019). Therefore, students need to understand that media outlets have, in general, commercial or governmental purposes (Cardoso and Gurgel, 2019; Höttecke and Allchin, 2020; Kellner and Share, 2019). This implies that even reputable media may occasionally prioritize sensationalism over scientific accuracy to attract new audiences (Reid and Norris, 2015).

Through this mediation process, specialized journalists serve as curators of scientific information, meaning they select

https://doi.org/10.26850/1678-4618.eq.v50.2025.e1530

what readers deem worthy of access (Höttecke and Allchin, 2020). Consequently, scientific information is adapted or reconstructed to reach non-specialist audiences. This transposition (or reconstruction) effort inevitably "alters" scientific knowledge and, in some cases, can make it inaccurate, especially when professionals involved do not have sufficient expertise on the subject in question (Cardoso and Gurgel, 2019). Besides, mediation efforts and the quality of scientific information published are impacted by the quantity of information sources and the time allocated for editing and publication (typically short due to the pressure to "publish first") (Reid and Norris, 2015). Therefore, the role of journalists is crucial in communicating science to the public, yet this mediation may lead to undesirable outcomes. For instance, in 1983, the Brazilian magazine Veja reported on a hybrid fruit supposedly made of tomato and cow fibers. However, the original story was an April Fools' joke published by the British magazine New Scientist, which Veja mistakenly presented as accurate and only retracted days later (Stroppa, 2018). On the other hand, some sectors of journalism have positively contributed to science communication by, over the last 70 years, highlighting the importance of scientific knowledge on the climate crisis and indirectly mobilizing political action (Höttecke and Allchin, 2020).

The merchandizing context analyzed by paper IV's author also extends the debate over the mentioned mediation process of scientific knowledge. Advertising primarily serves commercial interests, often at the expense of information quality. They typically offer minimal, if any, evidence, and the evidence for claims is frequently abbreviated or falsified (Belova and Eilks, 2015; Belova *et al.*, 2015; Kellner and Share, 2019). The enduring historical and cultural trust between the public and science remains a consistent element in advertising. This trust explains why scientific language and references to scientists are often emphasized to convey persuasive marketing messages—such as in the case of the filtering device analyzed in Paper IV, which falsely claims to reduce water acidity, while offering little rigor regarding the accuracy of the underlying concepts and procedures. Being well-informed about scientific knowledge and practices may be enough to avoid falling for misleading claims in advertisements (Dodds *et al.*, 2008). However, learning both with and about advertising, focusing on its rhetoric and convincing strategies, can increase even more chemistry's contribution to the development of science and media literacy (Belova and Eilks, 2015).

When it comes to social media such as Facebook, WhatsApp, and Instagram (platforms where all the messages analyzed by papers I and II broadly circulated through), their impact in the mediation of scientific knowledge increases and complexifies exponentially. This statement is supported by the evidence that false news is 70% more likely to be retweeted than fact-checked information (Vosoughi *et al.*, 2018). This tendency to overlook systematic and well-founded knowledge is explained by social media architecture (Kellner and Share, 2019). Some social media platforms were made for people to react and interact, via commenting, liking, reposting, sharing, upvoting, and so on, prioritizing popularity and summarized communication over information accuracy (Bimber and Zúñiga, 2020). The consistent impact of social media architecture on the quality of scientific information justifies its incorporation as a content into chemistry curricula, particularly when addressing issues of disinformation.

Social media architecture provides other important contents to address regarding how scientific information reaches out to the public. From the contexts analyzed by papers I and II, it is worth highlighting three important aspects: filter bubble, economy of attention, and eco chambers. While the internet offers unparalleled access to diverse information, it can also have the opposite effect by reinforcing existing beliefs and marginalizing opposing viewpoints (Pivaro and Girotto Júnior, 2020). The filter bubble effect is a consequence of the logic of communication behind social media, which, based on user's past behaviors, tailor personalized contents to please and keep them connected (Schulz and Roessler, 2012). This business model is called the attention market, through which big tech companies compete for users' attention, processing and selling it to advertisers (Wu, 2019). One side effect of this logic is the formation of echo chambers, communities on social media formed by people with similar preferences, where false scientific ideas are more likely to be endorsed than questioned or challenged (Höttecke and Allchin, 2020).

3.3. Values and ideologies

Characterizing certain misleading science-related information as disinformation, instead of fake news, post-truth or pseudoscience has one fundamental reason: to shade light on purposes and motivations of those who create and disseminate disinformation (Swire-Thompson and Lazer, 2022). This is why it is crucial to recognize the relationship between information and power, especially when cases of scientific disinformation are not merely due to a lack of scientific literacy but are instead driven by anti-democratic agendas (Arroio, 2020; Feinstein and Waddington, 2020; Pivaro and Girotto Júnior, 2020). For instance, the well-documented efforts of corporations to undermine the scientific consensus on the harmful effects of smoking and the reality of climate change are particularly notable (Oreskes and Conway, 2010). These controversies were intentionally manufactured to sideline science-based public policies and prioritize economic and ideological agendas. In her book *Why Trust Science*, Oreskes (2019) argues that the primary strategy of science deniers is to create the impression that the relevant science is unsettled and that the pertinent scientific issues are still open to debate. Oreskes' solution involves two dimensions, both explored in this paper. First, in dialogue with the Nature of Science's framework, she advocates teaching how science works, emphasizing that there are often sound reasons to trust established scientific claims. The second approach is to expose the ideological and economic motivations behind the science denial, revealing that the objections are not rooted in science but are instead political and ideological. For science educators, Valladares (2021) recommends revealing the conflicts of interest, ideological biases, and economic motivations behind science denial, emphasizing it as a political strategy to undermine public trust and highlighting the need to understand the social, political, economic, historical, and epistemic dynamics of science.

Therefore, efforts to discredit scientific knowledge without the epistemological rigor, or to sway public trust towards the "wrong science" (knowledge outside the specialist consensus) (Allchin, 2021), must be examined in the context of underlying values and ideologies. This approach will offer a deeper understanding of the scientific disinformation at hand. For instance, the messages analyzed in papers I and II propose simplistic and miraculous remedies to fight SARS-CoV-2, such as adopting an alkaline diet and using vinegar for hand sanitization. Simultaneously, these claims cast doubt on the health protocols recommended by expert-based organizations like the World Health Organization (WHO). In fact, usually behind movements like anti-vax and anti-mask –such as in the case of corporations trying to deny anthropological climate change– lay down anti-science, anti-technocratic, and anti-state views, along with the protection of values based on self-determination (Das and Ahmed, 2021; Oreskes, 2019).

In this sense, there is evidence that as science-literacy and numeracy increased among US-Americans, concern with climate change decreased, and what influences positive awareness among them is more cultural affiliation than scientific reasoning capacity (Kahan *et al.*, 2012). In another study, African-US-Americans presented lower trust in the national healthcare system, as a possible result of a legacy of racial discrimination in medical research and in the national health system (Boulware *et al.*, 2003). Therefore, to understand and then change how people grapple with scientific knowledge, it is necessary to comprehend their social and cultural context, addressing values, culture, history and ideologies (Feinstein and Waddington, 2020; Kahan *et al.*, 2012; Silva and Arroio, 2023). However, caution must be taken when conveying those contents in classroom to avoid the false conclusion that certain values and ideologies are anti-science by nature. Or even that to better understand or make science is necessary to adopt a "neutral perspective", treating values as corrupting influences. First, during the 1960s, the political left in USA criticized Science for its military applications, while today, those on the political right critique it for highlighting flaws in contemporary capitalism (Oreskes, 2019). Second, science's past and present give plenty of examples of when values have been in favor of a more humanized science. Socialist values, for example, were crucial to some geneticists' critique of eugenic thinking (Oreskes, 2019); and indigenous' philosophies have been decisive to improve the quality of scientific conclusions regarding analyses of risk and uncertainty in environmental disasters (Covitt and Anderson, 2022). In sum, science as an institution has historically been shaped by values - such as technical and economic progress (Lacey and Mariconda, 2014). This is no different for science education which today formally prioritizes practices, goals, and subjects that reflect values like social participation, emancipation, and justice (Silva and Sasseron, 2021; Silva and Arroio, 2023; Valladares, 2021).

Therefore, discussions around those contents seek to contribute to rethinking the teaching of acid-base theories in light of new cultural phenomena. It no longer makes sense for teaching to continue to focus solely on the transmission of traditional contents, given that they are covered in primary and secondary education, and after the many hours spent training students, they are still vulnerable to the information disorders circulating on social media (Osborne and Pimentel, 2023). Scientific education needs to contribute to the development of these students' critical thinking and certainly the teaching of acid-base theories content can lead to this criticality when they are embedded in today's social context.

4. Conclusions

This paper is grounded in the thesis that scientific disinformation and misinformation related to acid-base theories are more effectively addressed through multidisciplinary approaches. Integrating content from various fields enriches chemistry education by reflecting the complexity of contemporary, real-world issue. This approach promotes a more critical understanding and supports meaningful transformation within the contemporary information ecosystem, helping to mitigate its adverse impacts on society.

In this work, analyses of publications on how acid-base theories are addressed in cases of informational disorders revealed that a disciplinary approach heavily focused on chemistry content is often used to debunk erroneous messages, even when the contexts involve socioscientific issues like the COVID-19 pandemic. On the other hand, this work defends and gives examples of how other contents (nature of science; traditional and modern media functioning; and values and ideologies) can be brought together with acid-base theories to a better understanding of disinformation and misinformation discussed in the analyzed papers.

It should be noted that this paper does not present an exhaustive discussion of content possibilities. Other topics are equally relevant and encouraged, such as media language and semiotics, audience interpretation and positionality, and critical approaches to science. The possibilities are vast since critical thinking is not a formula, but a journey (Kovach and Rosenstiel, 2011). It is important to emphasize that merely addressing a catalog of content is not sufficient to generate meaningful change in addressing the harms caused by disinformation. Likewise, although teaching analytical procedures—such as identifying sources, genres, and formats of manipulated or falsified news—can be useful, they are not enough to tackle the complexity of the issue. What is required is the alignment of content with adequate resources, pedagogical principles, methodologies, goals, and competencies capable of fostering an education that is truly transformative.

Finally, the concepts of acids and bases are deeply intertwined with our daily lives. As the 100th anniversary of their theories approaches, this milestone offers an opportunity to reconsider how these concepts are taught and learned at all educational levels in an era dominated by social media. It is a chance to cultivate critical thinking in the current generation, laying the foundation for the next century of acid-base theories.

Authors' contribution

Conceptualization: Erasmo Moises dos Santos Silva; Agnaldo Arroio; **Data curation**: Erasmo Moises dos Santos Silva; **Formal Analysis**: Erasmo Moises dos Santos Silva; **Funding acquisition**: Not applicable; **Investigation**: Erasmo Moises dos Santos Silva; **Methodology**: Erasmo Moises dos Santos Silva; Agnaldo Arroio; **Project administration**: Agnaldo Arroio; **Resources**: Erasmo Moises dos Santos Silva; Agnaldo Arroio; **Software**:Erasmo Moises dos Santos Silva; Agnaldo Arroio; **Supervision**: Agnaldo Arroio; **Validation**: Agnaldo Arroio; **Visualization**: Erasmo Moises dos Santos Silva; Agnaldo Arroio; **Writing – original draft**: Erasmo Moises dos Santos Silva; **Writing – review & editing**: Erasmo Moises dos Santos Silva; Agnaldo Arroio.

Data availability statement

Data sharing is not applicable.

Funding

Not applicable.

Acknowledgments

Not applicable.

Conflict of interest

The authors declare that there is no conflict of interest.

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