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RESEARCH ARTICLE

Reading adapted scientific literature: A theoretical and qualitative assessment of its potential for promoting an understanding of nature of science

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Abstract
Reading authentic scientific literature is expected to have many positive effects on students, including the communication of various aspects about nature of science. Many different approaches are discussed, e.g., using a research article unchanged, adding comments and explanations to an article, or changing and adapting it. Common to all approaches is the underlying premise that the characteristic properties of scientific literature can promote nature of science in educational settings. To support this premise, this article first links selected structural and rhetorical features of scientific literature to aspects of the nature of science. We then report on our qualitative study of how reading an adaptation of a scientific review affects pre-service teachers' understanding of nature of science. The examined features of scientific literature point to aspects of nature of science. After our intervention, we observed a shift in participants' perception of the uncertainty of scientific knowledge, leading to a more accurate understanding, while changes on the empirical nature of scientific knowledge and as the subjectivity of scientists improved primarily among individual participants. From both a theoretical and an empirical point of view, our findings collectively suggest that engaging with authentic scientific literature in form of adapted literature can effectively promote an understanding of nature of science.

Keywords
adapted scientific literature; scientific literature; reading science; nature of science

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State of the literature
- Numerous studies have shown that students and even pre-service teachers often hold naive or inconsistent conceptions of the nature of science (NOS), especially regarding the tentativeness and subjectivity of scientific knowledge.
- Research has established that engaging with primary or adapted primary scientific literature (APL) can enhance aspects of scientific literacy, including understanding the structure of scientific arguments and the credibility of claims.
- Adapted primary literature has been used successfully in various educational settings, but there is limited research on the use of adapted review articles (ARA) and their potential to promote NOS understanding, particularly in the context of unresolved scientific controversies.

Contribution of this paper to the literature
- This study introduces and evaluates the use of an adapted review article (ARA) - a novel text type in science education research as a tool to foster pre-service teachers' understanding of NOS.
- It provides empirical insights into how specific aspects of NOS (tentativeness, empiricism, subjectivity) are addressed implicitly through reading ARA, using a contemporary and societally relevant case (glyphosate debate).
- The paper contributes a qualitative methodology to explore nuanced student responses, extending existing research on APL by focusing on reflection and belief change through written and verbal engagement with scientific discourse.

Introduction
To face scientific misinformation, Osborne and Pimentel (2022) call for a more comprehensive education on the social nature of science. Knowing more about the mechanism that science employs to establishing credibility, how scientific knowledge is generated and how a consensus emerges is of utmost importance to assess scientific information. To achieve this, science education necessitates enhanced standards and improved teacher training as well as the development of new curricular materials. Integrating authentic scientific literature, i.e., research articles from the scientific community, into educational processes at both school or university levels could be an answer to this demand. Research reports constitute the primary textual form within the scientific community and play a pivotal role in generating new knowledge (Goldman & Bisanz, 2002). Although they do not provide a precise description of the authors' thoughts and research process, they do reflect scientific practice and the prevailing views of the scientific community at that time (A. J. Meadows, 1985).

The concept of integrating authentic scientific literature into secondary education is not entirely new. Some educators use the unchanged paper (e.g., Rawlings, 2019), others annotate it (Hoskins, Lopatto, & Stevens, 2011), while some argue modifying and adapting the article is the best approach for readers with limited experiences with such literature (Yarden, Brill, & Falk, 2001). The specific language, the rhetoric of science (Harré, 1990), is an often-used argument for the

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employing of these genres in educational settings. Beyond conveying the scientific content itself, the objectives of these methods are often similar: enhancing the students' reading skills, critical thinking, understanding of nature of science (NOS) and fostering epistemological beliefs or ultimately enhancing scientific literacy among readers (Yarden et al., 2001; Falk, Brill, & Yarden, 2008; Hoskins et al., 2011; Braun & Nückles, 2014; Kararo & McCartney, 2019; Rawlings, 2019).

In this article, we provide an overview of the genre of adapted scientific literature, and discuss it's potential to influence students' and pre-service teachers' understanding of NOS. Building upon significant prior research on the impact of adapted primary literature (APL) on scientific literacy, we report on our experimental qualitative study in which we explored the effects of reading an adapted review article focused on the scientific disagreement surrounding the carcinogenicity of glyphosate on readers' understanding of NOS.

Theoretical Framework

Nature of Science

Numerous researchers, philosophers, historians and science educators try to elucidate the mechanism of science, its distinction from other entities and its fundamental nature – summarized under the term NOS. In general, NOS encompasses "the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Abd-El-Khalick, Bell, & Lederman, 1998, p. 418). There is no complete consensus on which aspects ultimately belong to NOS, which is why it is often avoided to use the article "the" before NOS (N. G. Lederman, 2006). However, discussions about the exact definition of NOS and the aspects included tend to be highly specific and therefore of more academic than practical-educational interest.

Nevertheless, science educators and researchers require a functional conceptualization of NOS. Based on this need, the group of Lederman defined three criteria to determine which NOS aspects are most relevant to science education:

1. Is knowledge of the aspect of NOS accessible to students (can they learn and understand)?
2. Is there general consensus about the aspect of NOS?
3. Is it useful for all citizens to understand the aspect of NOS? (N. G. Lederman, 2006, p. 304)

Guided by these questions, seven aspects of NOS were considered important by the group:

- Scientific knowledge is tentative
- Scientific knowledge is empirically-based
- Scientific knowledge is subjective
- Scientific knowledge necessarily involves human inference, imagination, and creativity
- Scientific knowledge is socially and culturally embedded
- The distinction between observations and inferences
- The functions of, and relationships between, scientific theories and laws (N. G. Lederman, 2006, p. 304; but also already mentioned by Abd-El-Khalick et al., 1998)

This list is also commonly referred to as "Lederman Seven" (Matthews, 2012) and is described in several publications but varies occasionally in the exact wording. Sometimes, the empirical-based nature of scientific knowledge and the distinction between observations and inferences are grouped as one aspect, while the myth of the scientific method is added as a new aspect (e.g. N. G. Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The Lederman Seven is the most common framework of NOS with the majority of instruments referring to this conceptualization, so it could be described as the most widely recognized (Clough, 2007; Galili, 2019; Matthews, 2012).

This conceptualization of NOS focuses mainly on the characteristics of scientific knowledge, which is why it should rather be called nature of scientific knowledge (NOSK; N. G. Lederman & Lederman, 2019). When focusing on scientific inquiry, the concept of nature of scientific inquiry (NOSI) describes meta-knowledge concerning the process of conducting science. Based on guiding principles and lists of general inquiry skills from various US-American research organizations, Lederman et al. identified eight aspects of NOSI, e.g., "scientific investigations all begin with a question and do not necessarily test a hypothesis" or "explanations are developed from a combination of collected data and what is already known" (J. S. Lederman et al., 2014, p. 68).

Criticisms have been raised in literature that decontextualized listing of aspects could encourage the communication of NOS in a declarative manner rather than promoting a genuine understanding (Allchin, 2011; Clough, 2007; Galili, 2019; Matthews, 2012). Learning NOS as a checklist neglects the complex nature of it. For instance, the characterization of science as tentative (see the list above) can be overemphasized, disregarding the durability of well-established statements. While Clough (2007) proposes transforming the NOS aspects into open questions (e.g., "In what sense is scientific knowledge tentative? In what sense is it durable?" or "To what extent are scientists and scientific knowledge subjective? To what extent can they be objective?"), which enables a context-specific view of the individual aspects, Allchin advocates for an emphasis on a functional (rather than a declarative) understanding on the reliability and credibility in science (Allchin, 2011, 2012). He argues that "reducing NOS instruction to a few standardized features prevents a full appreciation of the spectrum of scientific practice" (Allchin, 2012, p. 697) and suggests using historical or contemporary cases to teach the embedded NOS features. The consensus view does not reflect the important social interactions of scientists, so Allchin argues for incorporating such aspects to encompass the nature of whole science. This includes the role of funding or motivation of scientists as well as the peer review process, cognitive biases, fraud and the validation of new methods (Allchin, 2011). Highlighting the communicative aspects and the role of society, Höttecke and Allchin (2020) argue for the inclusion of media literacy in NOS education, leading to a conceptual shift from NOS to NOSIS (nature of science in society). NOSIS extends traditional NOS views by describing the dissemination of scientific information beyond the scientific consensus into society. Key NOSIS concepts are the "structure of knowledge and domains of discourse", e.g., credibility or consensus in science, the "public communication of science", e.g., mediation processes or conflict of interest in science communication, and the engagement "in a discourse of communication", e.g., confirmation bias or echo chamber effects (Höttecke & Allchin, 2020, p. 659).

Matthews (2012) proposes to change the terminology from nature of science (NOS) to features of science (FOS). This approach offers the advantage a more nuanced understanding of science, considering the process, the institutions involved, and the cultural and social context of knowledge production. Changing the terminology is not just a renaming: While the consensus view describes science like a list of facts, the FOS approach allows science to be characterized by features that may vary depending on the context, resulting in very distinct properties. This idea has been further explored by Irzik and Nola (2011, 2023), resulting in the Family Resemblance Approach (FRA), which has been adapted for science education by Dagher and Erduran (2016, 2023). Based on Ludwig Wittgenstein's (1953) concept of family resemblance, FRA suggests that science cannot be described by a static definition or by a fixed set of properties. Various scientific disciplines share similarities but can have both common and distinct characteristics. While all involve cognitive-epistemic and social aspects, the configuration of these two categories varies between them. The FRA has been broadly used in science education and science education research (Barak, 2023; Cheung & Erduran, 2023; Dagher & Erduran, 2016; Erduran, Dagher, & McDonald, 2019), e.g., in the analysis and development of curricular documents (e.g., Kostøl, Bøe, & Skår, 2023) and textbooks (e.g., Fricke & Reinisch, 2023; Okan & Kaya, 2023; Yeh, Dhurumraj, & Ramnarain, 2023) or in exploring teachers' views about NOS (e.g., Azninda, Raharjo, & Sunarti, 2021; Demirel, Sungur, & Çakıroğlu, 2023; Voss, Kent-Schneider, Kruse, & Daemicke, 2023). The given list of examples is by no means exhaustive.

Instead of merely contrasting the different approaches and regarding them as mutually exclusive, Kampourakis (2016) attempts to build a bridge between the concepts. According to him, the consensus view (which he names "general aspects") serves as a starting point for introducing students to NOS. He proposes that after providing students with a basic understanding of NOS with these general aspects, the FRA can be used to guide them towards a more sophisticated understanding of NOS. Since most aspects covered in both approaches are compatible with each other, using this approach does not lead to confusion among students.

Following this, we argue that several inherent NOS aspects can be derived from the ongoing case of the classification of glyphosate as carcinogenic (cf. section "about the scientific disagreement over the carcinogenicity of glyphosate"). In this instance, the International Agency for Research on Cancer (IARC) and the European Food Safety Authority (EFSA) arrived at different conclusions in their assessments (European Food Safety Authority, 2015; International Agency for Research on Cancer, 2015; Tarazona et al., 2017). This situation raises questions regarding of when scientific knowledge is certain, how it is acquired, and particularly, whether it is subjective. How can it be that two such prominent and significant institutions come to such contradictory scientific conclusions? To address this disagreement, we first define three selected NOS aspects that are important for answering the above questions: The tentative and (un)certain nature of science and scientific knowledge, the empirical nature of science and scientific knowledge and the subjectivity and objectivity inherent in science and among scientist. Subsequently, we connect these aspects with structural and linguistic characteristics of scientific articles.

Tentative nature and (un)certainty of science and scientific knowledge

One of the most crucial aspects of NOS is the inherent tentative nature and (un)certainty of scientific knowledge. In their article, Müller and Reiners (2023) reviewed this aspect in detail, considering both a philosophical-historical perspective and the perspective of science education. Here, we summarize the key findings relevant to this study; for a detailed review we want to refer to their article.

Scientific knowledge is generally described as uncertain. This includes facts, laws and theories (N. G. Lederman et al., 2002). The uncertainty or tentativeness can be understood and rationalized in (at least) two different ways. One argument frequently used refers to the philosophy of science of Karl Popper, the principle of falsification. According to Popper, scientific theories or laws can never be called ultimately true or absolutely verified because it is impossible to test every conceivable individual case they describe (Müller & Reiners, 2023; Popper, 1963). An alternative perspective on the uncertain and tentative character of science is often argued in terms of the possibility that new empirical evidence or the development of novel methods can lead to revised interpretations of previous observations, giving rise to the latest theories. This aligns with the empirically-based NOS and is often associated with other aspects of NOS, such as the cultural and social embeddedness of science or the subjectivity and creativity of involved scientist (Bell, 2006; Müller & Reiners, 2023; cf. Lederman Seven). The uncertainty of science constitutes a central and pivotal aspect for NOS and is reflected in scientific language, as we will argue later (c.f. section "Characteristics of (adapted) scientific literature and its educational potential").

As noted earlier, critics of the Lederman Seven or similar consensus lists often argue that the tentativeness of scientific knowledge is overemphasized. Not only is this an inappropriate oversimplification of the complex aspect, it could lead to students mistrusting science and questioning the validity of scientific knowledge (and education) (Clough, 2007; Cobern, 2020; Hodson, 2014).

This should especially be considered because school science is often presented as relatively certain (Dimopoulos & Karamanidou, 2013; Myers, 1992) and has been shown to be reliable knowledge over time (Galili, 2019).

Empirical nature of science and scientific knowledge

The aspect of the empirical nature of science and scientific knowledge is often described vaguely. Lederman characterizes it as “Scientific knowledge is […] based on and/or derived at least partially from observations of the natural world” (N. G. Lederman, 2006, p. 304), while these observations are filtered through our perception or instruments (N. G. Lederman et al., 2002). In this aspect usually lies the distinction between observations, inferences and theoretical entities. Observations are defined as descriptive statements about the world, which are directly assessable (e.g., an apple falling to the ground), while inferences are statements about natural phenomena, which are not directly assessable (e.g., gravity). Theoretical entities are unobservable constructs within theories (e.g., gravitational force).

Subjectivity and objectivity of science and scientists

Observations play a central role in the empirical nature of science and scientific knowledge, but they do not occur in isolation. An important and widely underestimated influencing factor in science are the scientists themselves. “Scientists’ theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work” (N. G. Lederman et al., 2002, p. 501). Despite the ideal of scientific objectivity and neutrality, all these factors influence the work of a scientist. This is also connected to the social and cultural embeddedness and the creative and imaginative NOS and scientific knowledge (cf. Lederman Seven). Every activity in science is influenced by the scientist’s “mindset” (N. G. Lederman et al., 2002).

This does not mean that science is entirely subjective. On the contrary, many mechanisms and self-correcting features like the peer-review process attempt to reduce the negative impact of subjective influences on scientific knowledge. This aspect is incorporated in the social character of science (Fernández, Benitez, & Romero-Maltrana, 2022).

Pre-service teachers' views about NOS and interventions for changing them

Although NOS has a long tradition of research and is generally considered important for scientific literacy, studies regularly show that teachers and students do not have an adequate understanding of NOS (Deng, Chen, Tsai, & Chai, 2011; N. G. Lederman, 2007). To address this issue, apart from established pedagogical methods for teaching NOS it is essential for teachers to hold accurate NOS beliefs (N. G. Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Therefore, optimization of educational programs of pre-service teachers is considered highly beneficial equipping them with the necessary understanding and tools to teach NOS in the future. In the following, we will present a selection of research on pre-service teachers; for results on students or in-service teachers, we want to refer to reviews from Abd-El-Khalick and Lederman (2000), Bugingo et al. (2022) and Khishfe (2022).

In their meta-study, Cofré et al. (2019) analyzed 52 studies to detect patterns in teaching and learning NOS regarding students, pre- and in-service science teachers. 16 studies were related to pre-service teachers' understandings, including nine studies of elementary teachers and seven of secondary teachers. The results of the majority of the studies demonstrated that most pre-service teachers held naive views about scientific theories and laws prior to the respective intervention. Pre-service elementary teachers generally exhibited more informed views of empirically-based NOS (Abd-El-Khalick & Akerson, 2009; e.g., Matkins & Bell, 2007), a trend not consistently observed among pre-service secondary teachers (e.g., Seung, Bryan, & Butler, 2009). Following interventions, typically lasting a semester and combines many different strategies like discussions, hands-on experiments, readings etc., participants showed the most improvement in aspects where they initially held the least informed views. Consequently, the majority of studies detected a weak improvement on views of the empirical NOS by the employed interventions (Cofré et al., 2019).

Concerning the subjective and theory-laden NOS, no clear picture can be distilled from the literature. Interventions from Abd-El-Khalick and Akerson (2009), Matkins and Bell (2007) and Ozgelen et al. (2013) demonstrated substantial improvements in this aspect, while Abd-El-Khalick (2005) and Akerson et al. (2000) report more modest improvements for their courses. With the exception of Seung et al. (2009), participants mostly held naive views on this aspect prior to the respective intervention. Nevertheless, improvement of the subjective NOS was among the lowest compared to other tested aspects, alongside the socio-cultural embedded and tentative NOS (Cofré et al., 2019).

Müller and Reiners (2023) observed a similar effect concerning pre-service teachers’ view of the tentativeness of science. The majority of participants exhibited inconsistent or partially informed views on the tentative NOS which remained relatively resistant to change after a 5-week intervention. The observed resistance aligns with results from Mesci and Schwartz (2017), while Akerson et al. (2000) or Abd-El-Khalick and Akerson (2009) report a substantial improvement following their intervention. Generally, the literature usually reports a naive view concerning this aspect by pre-teachers (Cofré et al., 2019).

Targeting the pre-service teachers’ instructional views, Voss et al. (2023) developed a semester-long NOS course guided by the FRA wheel for pre-service teachers. They aimed at fostering not only the understanding of NOS but also the knowledge needed to teach NOS. The evaluation of the course focused on the participants pedagogical and instructional views, instead of the views

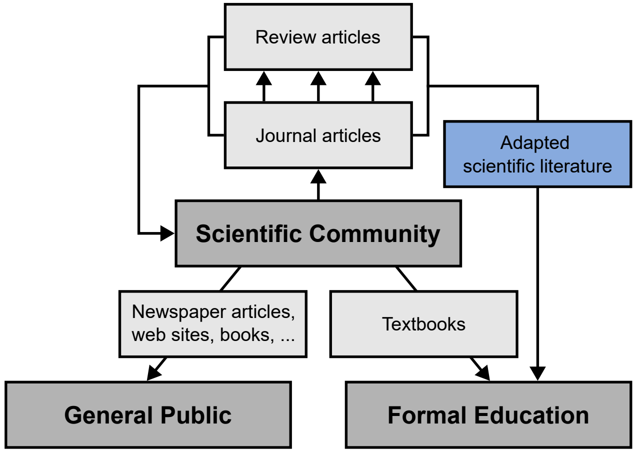

Figure 1. Overview of the major sociocultural roles in science communication and their mainly used text genres. The illustration is adapted from Aljets and Waitz (2023), theoretically based on the work of Goldman and Bisanz (2002) and augmented by the concept of adapted scientific literature. Originating in the scientific community, scientific knowledge is communicated to scientists, popularized to the general public, and provided for the formal education through specific text genres like journal and review articles, newspaper articles and textbooks, respectively. Combined under the umbrella term adapted scientific literature, adapted primary literature (APL) and adapted review articles (ARA) are new hybrid genres, which are reduced forms of scientific literature and are directed to the formal education (Hoff et al. 2019; Yarden, Phillips, & Norris, 2015).

about NOS itself. Over the course, the participants views shifted from implicit teaching to explicit-reflective instructions and to targeting specific NOS aspects. However, the pre-service teachers encountered difficulties with the teaching of social-institutional NOS, often avoiding the social dimensions of science.

In summary, studies consistently report an inadequate general view about NOS among pre-service teachers, which is a concern given their pivotal role in future education. In tendency, views on the empirical-based NOS do not seem to be as naive as, for example, views on tentativeness or subjectivity. Various teaching concepts including history of science, reflective discussions, hands-on-activities etc. show promising effects on elaborating beliefs about NOS, although the reported outcome is not consistent. This demonstrates the ongoing need for the development and evaluation of novel innovative interventions to enhance the views on NOS of pre-service teachers.

Written science communication

Science communication is an expression of the social character of science and constitutes a diverse field with many different communication methods. Focusing on written science communication, Goldman and Bisanz (2002) distinguish three major sociocultural roles for disseminating scientific information: (1) communicating among scientists, (2) popularizing information to the general public and (3) providing formal education. Each of these roles is characterized by distinct forms of communication with characteristic properties, tailored to the needs of the target audience. **Figure 1** provides a model of the main sociocultural roles and their dominant text genres, complemented by the new genre of adapted scientific literature (ASL).

Key genre for the scientific community is the research article, which is the foundation for all subsequent scientific communications (Swales, 1990). Reporting on research results in a journal article among of the most crucial tools employed by the scientific community to gain new knowledge. Only by communicating and debating research results, ideas and theories, the scientific community can evaluate and accumulate new knowledge claims (Goldman & Bisanz, 2002; Arthur Jack Meadows, 1998). An integral step in this scientific publication process is peer review, which serves as a mechanism for quality control. Ideally, the peer review process assists the community to self-regulate and ensures that scientists adhere to the shared standards and values of science (Lee, Sugimoto, Zhang, & Cronin, 2013; Arthur Jack Meadows, 1998). The selected reviewers act as referees, responsible for evaluating if the manuscript meets these standards and values. Articles that successfully pass this process are eligible to be published in the journal, bearing the "stamp of approval" of the scientific community (Goldman & Bisanz, 2002, p. 24). However, the system is not free of biases and flaws, and its effectiveness remains empirically unclear (Jefferson, Wager, & Davidoff, 2002; Lee et al., 2013; Arthur Jack Meadows, 1998).

Nevertheless, even after the peer-review process outlined above, conflicting and inconsistent research results are published. By "gathering research, getting rid of rubbish and summarizing the best of what remains" (Grant & Booth, 2009, p. 92), review articles fill this gap. These articles distill the current state of knowledge on a specific topic, propose new research avenues and highlight open questions (Goldman & Bisanz, 2002). Over the course of the 20th century, systematic review methods develop, resulting in various subtypes of review articles (Grant & Booth, 2009; Paré, Trudel, Jaana, & Kitsiou, 2015). By referencing to important research articles, reviews document the scientific consensus in a research discipline. Moreover, this consensus is also shaped significantly by citations. As they signify the acceptance of specific ideas, citation of research and review articles are a good indicator of agreement, because they suggest which ideas and theories are gaining acceptance. In fact, the analysis of citation networks can be used to model consensus formation (Nicolaisen & Frandsen, 2012; e.g., Shwed & Bearman, 2010). A terminological debate about whether review articles still belong to primary scientific literature or are to be described as secondary is in our opinion not fruitful and falls beyond the scope of this work. However, because review articles are based on other research reports and do not report new experiments, they are typically classified as secondary literature.

With the term adapted scientific literature (ASL) we want to subsume adaptations of scientific literature, and therefore refer to the adapted primary literature (APL) described by Yarden et al. (2001, 2015), which mainly focuses on journal articles, as well as to adaptations of review articles, which we denote as adapted review articles (ARA). Adapted scientific texts represent modified versions of original scientific texts like research or review articles. Goal of the adaptation is to conserve the structural and rhetorical features of the original texts while making them more accessible to students (Yarden et al., 2001, 2015). Original scientific literature assumes a high degree of prior knowledge from the reader and relies heavily on background knowledge within a specific scientific field. Even for scientists from neighboring fields of research, reading articles outside their domain can be challenging (Bazerman, 1985). This difficulty is amplified for students who lack experience with the text structures and are confronted with a dense array of details and unfamiliar research methods (Goldman & Bisanz, 2002; Yarden et al., 2001). The adaptation process consists of several steps: removing details from the methods and the results section, expanding the introduction section with necessary background information, and adding context to the discussion section, rendering the article more understandable for novices (Yarden et al., 2001, 2015).

To our knowledge, the adaptation of review articles presents a novel approach and has not been reported previously. Therefore, we must answer the question why review articles should be adapted. As discussed above, research articles report new scientific findings, whereas reviews compare these and present the current state of knowledge and open questions. Thereby, they make a significant contribution to the process of establishing a scientific consensus. By comparing the results of different researchers over a period of time, employing different methods and producing sometimes contradictory results, reviews document the genesis of new scientific knowledge. In comparison, original research articles provide a brief and highly specific snapshot of this process. While the results of a research article are contextualized in the introduction and discussion (cf. the following section), the big picture unfolds through the intensive reflection of the research field as in a review article. Authors of reviews "[shape] the literature of a field into a story in order to enlist the support of readers to continue that story" (Myers, 1991, p. 45), making reviews the best opportunity for constructing new knowledge claims (Sinding, 1996).

Confronted with an overwhelming amount of research articles, scientist read review articles to keep informed, especially if they are new to a scientific field (Pautasso, 2013; Sinding, 1996). This is due to the simplification of research that a review accomplishes: Not only do they filter the literature, they also demonstrate relationships between them, presenting research findings in a highly processed manner (McMahan & McFarland, 2021). This suggests that reviews might be less challenging to understand than original research articles due to their more approachable nature. However, this assumption has to be tested empirically.

In summary, the considerations of this section lead us to assert that, when introducing novices to written scientific communication, review articles are indispensable because they form an integral part of the communication process. While research articles (or APL) show a detailed picture of the scientific process, review articles (or ARA) take a step back and show this process in a broadened perspective. With their different focus, both types of texts can provide the reader with an insight into scientific research and therefore present aspects of NOS.

Characteristics of (adapted) scientific literature and its educational potential

According to Fang, "scientific writing contains a number of unique features that encode specialized knowledge, values, and worldviews of the scientific community" (2005, p. 343). This suggests that NOS aspects can be derived from scientific literature. We argue that there exists an inherent educational potential within authentic scientific literature for fostering a deeper understanding of NOS.

Compared to the common genre of textbooks, (primary) scientific literature exhibits distinctive features like an organizational structure and specific rhetorical motives. Perhaps the most recognizable feature is the organizational structure, i.e., the division of the text into separate sections. In a rough classification, a scientific article in its more or less modern form[1] is divided into three parts (in tradition of western writing): Introduction, Procedure/Experiment and Discussion (Goldman & Bisanz, 2002; Hill, Soppelsa, & West, 1982). While the introduction guides the reader from a broad academic field to the particular topic of the paper, the discussion transitions back to a wider academic context. In between, the procedure section describes the experiment or theoretical problem (Hill et al., 1982). After World War II, the so-called IMRaD structure (Introduction, Methods, Results, and Discussion) developed, becoming dominant in the 1980s (Day, 1989; Sollaci & Pereira, 2004; Wu, 2011). However, it's important to note that this structure primarily applies to journal articles in the natural sciences, which we will focus on in the following discussion. Additionally, while review articles do not strictly adhere to the IMRaD structure, they typically consist of three distinct parts. This IMRaD structure is typical

[1] *Documenting and reporting scientific results has a long tradition and evolved over time from a letter form to a report we know today. The report, initially purely descriptive in chronological order, has prevailed over the letter form. It was not until the second half of the 19th century that a description of the used methods is included, so that the three-part theory, experiment, and discussion in experimental articles subsequently developed (Atkinson, 1999). Thus, by "modern form" we mean such articles. For more details on the history of (western) scientific publications, we want to refer to Kronick (1962) and Atkinson (1999).*

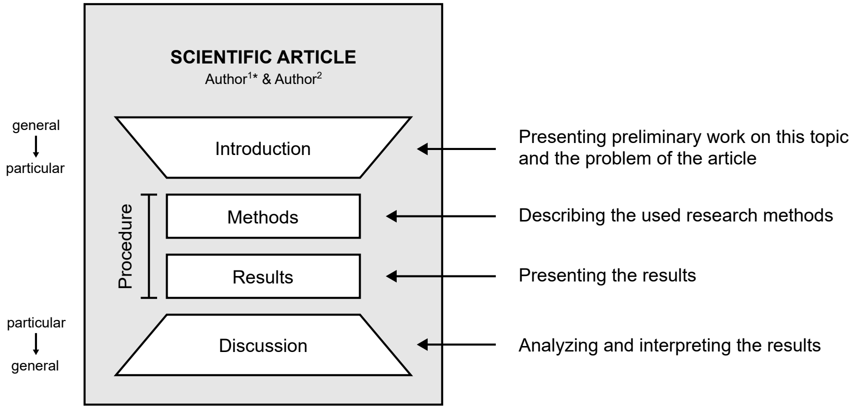

Figure 2. Illustration of the organizational structure of a typical original scientific research article. The organization of a scientific article follows the IMRaD pattern and its function (Harmon, 1989; Suppe, 1998; Wu, 2011). Most review articles usually do not follow the IMRaD structure. The graphic shows the three parted structure of a scientific article (Introduction – Procedure – Discussion). The width indicates how general (wider) or particular (narrower) the section is. Graphic based on Hill et al. (1982).

for experimental articles, although theoretical papers are very similar (Harmon, 1992; Yarden et al., 2015).

Each section serves a specific function (**Figure 2**). In the introduction, previous results, theories and viewpoints from the authors and other scientific groups are presented to develop the problem addressed in the article. This serves to justify the authors research work, shows its significance and the authors present themselves as a "competent colleague" (Hyland, 2010, p. 126) and establish their credibility (Goldman & Bisanz, 2002; Harmon, 1989; Suppe, 1998). In the Methods section, the methods employed are described so that the experimental design and the origin of the observations are transparent to the reader. This theoretically opens the replication of the data (Harmon, 1989; Suppe, 1998). Subsequently, the findings will be presented in the Results section. This is usually done both in a verbalized form, as well as with the support of tables, charts and graphs (Harmon, 1989). The results are then analyzed and interpreted in the Discussion section. Here, the authors also weigh uncertainties and biases, and assess the reliability of their interpretation. Furthermore, objections to the claims made in the article are discussed and contextualized with literature (Goldman & Bisanz, 2002; Harmon, 1989; Suppe, 1998).

The separation of scientific articles into results (observations) and discussion (inferences) already highlights an important aspect of NOS, woven into its organizational structure. From the aforementioned description of the IMRaD structure, it can also be concluded that both the methods and results sections tend to be more descriptive, while the introduction and discussion lean towards being more argumentative. Arguing about the status of scientific statements is combined with two noteworthy linguistic features of a scientific texts: the rhetorical figure called hedging and the use of references to the publications of colleagues.

Hyland (1994, 1998) defines hedging as a linguistic means used by authors to convey a lack of complete reliance on the absolute truth of a statement or a desire not to make a commitment. It can be expressed through various methods, e.g., the use of auxiliary verbs (*may*, *might*, *could*), or adjectival, adverbial and nominal modal expressions (*possible*, *perhaps*, *probability*). Hedging is frequently employed both in the introduction and discussion section of an article (Atanassova, Rey, & Bertin, 2018) and is essential for science and scientific writing. By weakening the assertiveness of scientific statements, hedging renders science open to discussion, allow contradiction and emphasizes the possibility to be wrong, thereby highlighting the tentative nature of scientific knowledge. Hedging also reflects the social dimension of science: "Scientific 'truth' is as much a social as an intellectual category, and the need to convince one's fellow scientists of the facticity of experimental results explains the widespread use of hedges in science and academic discourse" (Hyland, 1994, p. 241).

The analysis of the use of references points in a similar direction. Bertin et al. (2016) showed, that references are mainly used in the introduction and discussion sections and are therefore in a relationship with the argumentative structure of a paper. More generally, references express the use of the work of other scientists and therefore that scientific results are building on previous work.

Up until this point, we derived NOS aspects from the linguistic properties of primary scientific literature and have implicitly assumed that the adaptation of an article does not alter these distinct linguistic features. This presumption is supported by the results of the systemic functional linguistics analysis of Ariely et al. (2019). In their analysis, a research article (Davoodi-Semiromi et al., 2010), an adaptation from the article and a popular science article were analyzed concerning five linguistic properties: informational density, abstraction, technicality, authoritativeness, and hedging. In comparison to the original, the APL article exhibited a lower lexical complexity, while staying authentic to the research article and preserving other linguistic features.

Scientific communication, e.g., in form of (adapted) scientific articles, inherently mirrors the characteristics of science and views of scientists about science (Fang, 2005; Goldman & Bisanz, 2002). Based on the previous considerations, we believe that this inherent connection can be harnessed as an effective tool for teaching NOS.

Empirical research findings about reading APL in education

The most prominent text genre in formal education is the textbook, whose purpose is to convey well-established facts. Science textbooks present science as certain and focus on conveying scientific facts rather than on the process of gathering those same facts (Dimopoulos & Karamanidou, 2013; Goldman & Bisanz, 2002; Myers, 1992). Dimopoulos and Karamanidou even describe the science of school textbooks as "static and final" (2013, p. 61) and conclude:

> "[T]he basic characteristic of school science is its transcendency and, consequently, the concealment of evidence which can corroborate the idea that it is a 'construction' or a product resulting from processes taking place in the context of specific epistemic, cultural, political, financial, or other influences." (2013, p. 62)

One of the primary motivations to use authentic scientific literature in the form of primary scientific literature in education is its distinctive linguistic and textual characteristics. Yet, there are different approaches in terms of the actual form of the texts as well as the target audience. Some educators and researchers opt for original unaltered scientific articles (Laslo & Hartmann, 2023; e.g., Rawlings, 2019; Schmid, Dunk, & Wiles, 2021) others annotate them with explanations and definitions (e.g., Hoskins et al., 2011; Kararo & McCartney, 2019), while others adapt them moderately to heavily like APL (e.g., Authors 2019 [names deleted to maintain the integrity of the review process], Baram-Tsabari & Yarden, 2005; Falk et al., 2008; Norris, Stelnicki, & Vries, 2012; Phillips & Norris, 2009;). Some groups also compared the effects of these various formats (Braun & Nückles, 2014; McCartney, Wan, Griep, & Lighthall, 2023). However, it remains uncertain whether the different approaches equally effect on the readers' understanding of NOS.

A study by Brill and Yarden (2003) sought to determine whether learning through research papers could enhance the question-asking abilities of high-school students. They compared a group of Israeli high-school students (11th and 12th grade, $N = 87$) introduced to the curricular unit about developmental biology developed by Yarden et al. (2001), which includes four APL article. A control group (11th grade, $N = 38$) learned about genetics and through traditional textbooks. Initially, all students posed simple questions about properties of objects. In the experimental group, this evolved throughout the intervention into questions comparing or finding relationships between entities, indicative of higher-order thinking. This transformation was absent in the control group. The authors hypothesize that this could be attributed to the exposure of the entire research process, which enabled the students to understand the results and the methods behind the conclusions. This resulted in more questions to the methods of the research and ultimately makes it possible to criticize the research or formulate new research inquiries.

Baram-Tsabari and Yarden (2005) compared the effects of reading APL with popular-scientific articles on the scientific literacy of Israeli high school students (10th–12th grade, $N = 272$). Both texts are based on a scientific article from *Nature Biotechnology* by Mourez et al. (2001) about the design process of a polyvalent inhibitor to the anthrax toxin. The students who read the APL exhibited improved inquiry skills, while the other performed better on comprehension tests. As the content of the texts was mostly identical, Baram-Tsabari and Yarden attributed this result to the differing text structures, originating from their respective genres.

Motivated by this, Norris et al. (2012) reproduced the results of this study with high school students in Canada (12th grade, $N = 211$). While they maintained the same experimental design with a translation of the instruments of Baram-Tsabari and Yarden, their text revolved around a mathematical model of the West Nile virus spread (Wonham, de-Camino-Beck, & Lewis, 2004). Despite numerous differences from the Israeli study (demography of the participants, experimental vs. theoretical paper, topic, language, etc.), Norris et al. observed similar effects concerning critical thinking skills (in favor of the APL article) and text comprehension (to the disfavor of the APL article).

A subsequent study by Braun and Nückles (2014) compared four text types: a research article, a modified research article (APL), a popular-scientific article and a textbook chapter. The research and the APL article were based on a paper about the tool behavior of the New Caledonian crow (Chappell & Kacelnik, 2004), while the popular scientific article was drawing from multiple sources on this topic. The textbook chapter was taken from a high school biology textbook which summarizes the study by Chappel & Kacelnik. High school students (11th–12th grade, $N = 78$) were randomly assigned to these texts and their epistemological understanding was assessed across three dimensions: certainty, source and justification of knowledge. Only in the dimension justification of knowledge students showed a significant improvement after reading the original or adapted article. Text comprehension results did not differ significantly.

Partly based on Braun and Nückles, Hagen et al. (2022) tested text comprehension and effects on epistemological beliefs of educational science students (4th semester, $N = 74$) after reading APL, primary scientific literature or a textbook chapter. Participants who read APL exhibited significantly better text comprehension and more nuanced epistemological beliefs, particularly in the dimension of source of knowledge, compared to those exposed to the other texts. In contrast to the previous studies, the authors did not employ a natural science article, but instead a research article on the effects of homework on learning success in mathematics (Trautwein, Köller, & Baumert, 2001).

In the manuscript from Hagen et al. (2023), published in the dissertation by Hagen (2023), two studies on APL are reported. The first study replicates the findings of Hagen et al. (2022) with first-year university students ($N = 114$). Here, students reading APL demonstrated a significantly greater text comprehension compared to those using the textbook. Concerning the epistemological beliefs, significant results were found for source of knowledge and justification of knowledge in favor for the APL. Secondly, Hagen et al. investigated the benefits of prompting for reading APL (1st year university students, N = 74). This resulted in an enhanced text comprehension but did not significantly alter epistemological beliefs compared to the non-prompting group.

Von Hoff et al. (2019) investigated the use of APL to disseminate scientific research in a science outreach project. They adapted a research article from *Biophysical Journal* on the opening and closing mechanism of a voltage-dependent anion channel (Briones et al., 2016). In their study, they conducted a semi-structured interview with five high school students (11th grade) before and after reading the APL. The primary outcome was a transformation in students' understanding of how scientific knowledge is acquired, which the authors attributed to both the structure of the APL text and the introduction of the unfamiliar molecular dynamics simulation method.

Across these diverse studies, a positive influence of reading APL on scientific literacy, epistemological beliefs or NOS related concepts is consistently reported, while results on text comprehension vary (Baram-Tsabari & Yarden, 2005; Braun & Nückles, 2014; Hagen et al., 2022, 2023; Norris et al., 2012; von Hoff et al., 2019). The discussed studies differ over many variables: study design, topic of the APL article, experimental or theoretical methods in the article, demographics of the participants, country and education system, etc. Despite these differences, all authors contributed the observed effects of APL to its structural features. While direct comparisons may be challenging due to difference in the used and examined conceptualization of NOS, scientific literacy etc., it can be argued that they are nevertheless strongly related.

About the scientific disagreement over the carcinogenicity of glyphosate

In addition to linguistic features, the content of a paper also has potential to promote NOS. The article we adapted for this study, discusses the scientific basis for the contrasting assessments of glyphosate by IARC and EFSA (Tarazona et al., 2017).

In March 2015, IARC concluded that glyphosate and glyphosate-containing products are probably carcinogenic to humans (Guyton et al., 2015; International Agency for Research on Cancer, 2015). This decision evoked a reevaluation on the European side, ultimately yielding a divergent conclusion and intense scientific and societal discourse (European Food Safety Authority, 2015; Tarazona et al., 2017).

Glyphosate is currently approved in the EU until December 15, 2033 (Regulation 2023/2660). As the majority of EU member states neither voted in favor of nor against approval in the 2023 approval process, the 10-years-extension was decided by the EU Commission under stricter conditions (European Commission, 2023). In their latest risk assessment from May 2022, the European Chemicals Agency (ECHA) assessed the hazardous properties of glyphosate and retained its previous classification (European Chemicals Agency, 2022). Meanwhile, EFSA reexamined the impact of glyphosate on the health of humans, animals and the environment in 2023 and concluded that glyphosate does not meet the scientific criteria for classification as a cancerogenic, mutagenic or reprotoxic substance. However, data gaps were identified in some areas, particular in areas such as the consumer dietary risk assessment or the risk assessment of aquatic plants (European Food Safety Authority, 2023).

In their analysis, Tarazona et al. (2017) came to the conclusion, that the divergent evaluation results of IARC and EFSA of 2015 are based on different evidence and information sources, different methodology and different overall objectives. Particularly interesting for NOS education is that both institutions interpret the results of animal studies differently, thus highlighting the disparity between observations and conclusions. It underlines that the latter, while not arbitrary, is a subjective process. This recognizes that distinct arguments can yield differing conclusions from the same observations, demonstrating that science doesn't always follow a linear path to the same outcome.

Contemporary cases like this possess the advantage, that they are unsolved. Allchin et al. put this succinctly: "The drama of uncertainty is one reason why they are compelling vehicles for NOS education in the classroom" (2014, p. 466). Contrasting, using historic controversies carries the risk of fostering a simplified picture of science and the impressions that scientific knowledge necessarily progresses linearly to our present understanding (Allchin, 2003; Allchin et al., 2014). Potential NOS aspects that contemporary cases can foster include the uncertainty, tentativeness, subjectivity, multiple perspectives, the role of funding, political interests, and social embeddedness of science (Allchin et al., 2014).

Adaptation of the article

The debate over the carcinogenicity of glyphosate provides an opportunity to shed light on numerous NOS aspects due to the contrasting viewpoints between two prominent scientific agencies (IARC and EFSA). Consequently, an article describing and summarizing this debate was chosen for this study. The original article, titled "Glyphosate toxicity and carcinogenicity: a review of the scientific basis of the European Union assessment and its differences with IARC" by Tarazona et al. (2017), was published in *Archives of Toxicology* and reviews the debate and the reasons for the disagreement. The text used in our study is a modified version, guided by the adapted primary literature framework conceived by Yarden et al. (2015)

Yarden et al. recommend only classic research articles for adaptation, as other text formats such as review articles and book chapters typically lack important, characteristic features. However, if they still should be used, they would have to be adapted intensively. Despite this, the used article by Tarazona et al. fulfills most characteristics of a research article and shows similarities to a canonical structure (IMRaD), although it does not contain a Results section. In addition, the article summarizes the background to the evaluations well, rendering it particularly suitable for students with limited prior knowledge of the carcinogenicity debate.

Table 1. A summary of performed steps for the adaption of the article. The original step number refers to the suggested steps by Yarden et al. (2015, p. 95).

Step	Performed action	Original step no.
1	Selection of a PSL article	I.
2	Defining the necessary background knowledge	II.
3	Detailed summary of the article (paragraph by paragraph)	
4	Selection of the discussion points	III.*
5	Selection and additional creation of data representation	IV.
6	Re-writing of the Discussion section	VIII.
7	Re-writing of the Methods section	VI.
8	Re-writing of the Introduction section	VII.
9	Re-writing of the Conclusion section	
10	Re-writing of the Title	IX.
11	Re-writing of the Abstract section	X.

* In the original, step III is called "Choose results" (Yarden et al., 2015, p. 95). As we are adapting a review article, the selection of discussion points is equivalent to this.

Our choice to adapt this review article is based on the question on why the agencies differ in their conclusion on the cancerogenic potential of glyphosate. The authors systematically compare the two conclusions, document the differences, and discuss possible underlying factors causing them. This is particularly interesting when EFSA and IARC draw different conclusions from the very same studies that reported on the tumor incidence in male mice. Ultimately, this touches on one of the most recurring questions in science: Are these results based on correlation or chance? Or to be specific for this scenario: Can a carcinogenic potential be conclusively asserted based on these observations of increased tumor incidences? Both views have their merit and can be supported by arguments, thus it depends on the individual scientist's judgement which arguments they consider to be more compelling.

One single research study alone cannot resolve the question of whether glyphosate can cause cancer in humans and, as the review shows, even despite numerous research findings, the picture is still not very clear and highly controversial. The review demonstrates why the interpretation of research results is subjective, why not all scientists inevitably arrive at the same conclusion, and how scientists deal with the inherent uncertainty of scientific findings.

The original text contains 7,199 words – excluding the references, 10 tables, and 2 figures – on a total of 21 pages. For several reasons, we decided to adapt this article instead of using the original or a version translated to German: First, its lengths renders it impractical for seminar readings; second, too much prior knowledge (e.g., technical terms, abbreviations, procedures) is still necessary to understand the text; and third, the large amount of details, especially due to the 10 tables, may overwhelm inexperienced readers. To overcome these difficulties, we adapted the text as summarized in Table 1. To illustrate how we adapted the article, Table 2 offers two examples from the original article alongside their corresponding adaptations. Furthermore, we have included a comprehensive list of explanations for all abbreviations at the end of the text and provided explanations upon their initial introduction.

Table 2. Comparison between the original article and the adapted version. Two examples passages from Tarazona et al. (2017, pp. 2731 and 2734), the corresponding passage in our adaptation and a comment on the adaptation are given. Please note that the adapted article was written in German and the given examples had to be translated for this article.

Original article	Adapted article	Comment on the adaptation
Excessive toxicity, for instance toxicity at doses exceeding the MTD, can cause effects such as cell death (necrosis) with associated regenerative hyperplasia, which in turn can lead to tumour development as a secondary effect, unrelated to the intrinsic potential of the substance itself to cause tumours at lower and less toxic doses (European Chemicals Agency 2015; Knight et al. 2006).	High doses of a substance, e.g., doses above the MTD, can cause necrosis (cell death), which is associated with the development of tumors. However, this is considered to be a secondary effect because the substance does not intrinsically cause cancer at low doses and tumor formation is due to necrosis (ECHA, 2015; Knight et al., 2006).	• The linkage between the MTD (Maximum Tolerable Dose) and necrosis was simplified • Hedging was conserved • Citation was conserved MTD was explained at a previous position in the text and is also listed in a list of abbreviations
Regarding in vivo mammalian studies, IARC reports positive effects for 5 out of 11 studies; four negative studies on micronucleus formation and dominant lethal mutation reported by JMPR (2006) are not included in the IARC evaluation. Positive effects are described only for intraperitoneal administrations at doses of 300 mg/kg bw.	In total, the IARC reviewed eleven in vivo studies with mammalian cells, five of which reported genotoxic effects. These five studies have in common that they show positive results only at doses above 300 mg/kg body weight which are injected via the abdominal cavity.	• Shortening of the content • Replacing "bw" with "body weight" Paraphrasing the technical term "intraperitoneal administrations"

The final adapted article is 9 pages long with the main text containing 2,447 words (4,156 words in total). For an authentic adaptation and to show the importance of science communication among scientist, we decided to include the acknowledgements and references used in the text, although Yarden et al. (2015) do not. We also created a new figure elucidating tumor incidence data in relation to glyphosate dose in male CD-1 mice and shortened a table summarizing both the considered and dismissed studies in the review process by IARC and EFSA, respectively.

Aim of Study

The presented study aims to explore the impact of ASL on student's perception/beliefs of NOS. Research articles and modified research articles communicate their epistemological assumptions implicitly through stylistic and rhetorical features, as discussed previously. Given the limiting existing research on APL, our study seeks to contribute to this field and, in addition, establish connections between NOS and APL or ASL, respectively.

Based on these considerations, we investigated the potential for implicit changes in students' beliefs about NOS as a result of working with adapted scientific literature. More specifically, our research question was as follows: Does exposure to an adapted review article lead to changes in student's view on the tentative and (un)certain nature of scientific knowledge, the empirical nature of science and scientific knowledge and/or the subjectivity and objectivity of science and scientists? We decided to use an implicit approach in order to determine the fundamental potential of the material.

Methods

Design

To investigate the impact on students' views of NOS, we followed a qualitative research design. The intervention took place in the final session of a chemistry education seminar in 2021. The seminar is mandatory for students in teacher training and teaches basic knowledge and methods for planning and evaluating chemistry classes for secondary education. Due to COVID-19 safety regulations, the seminar was conducted via a videoconference tool and was recorded. The materials for the seminar were provided in digital form. The seminar was held entirely in German language.

One week before the intervention, the students were informed about the technical procedure of the study and their data protection rights. Special attention was drawn to the voluntary nature of their participation, the lack of grading, and that there were no right or wrong answers.

The main study is planned in 4 different parts (**Table 3**). After a brief presentation about the model of the three main roles in science communication (communication within the scientific community, popularization for the general public and education; compare with **Figure 1**), students were asked to answer a pretest about NOS and their previous experience with primary scientific literature. This was done by individually filling out a document. In the second part, a brief presentation on glyphosate and an introduction to the dispute between IARC and EFSA concerning the potential carcinogenicity of glyphosate. Subsequently, the students read the adapted review article, and posttest assessed their comprehension of the material, and their views on NOS. In the third part, possible comprehension problems were first clarified and then a discussion about NOS was conducted. The study design was completed by semi-structured group interviews to reflect on the learning effect of the seminar, which were conducted after the seminar. Students were requested to upload their pre- and posttest files.

Table 3. Study Design. The study is divided into four sections, with evaluation taking place at the end of each section. A detailed description of each section is given in the text.

Section	Content / Activity	Approx. time
I. Scientific Literature	Introduction - Data protection and handling - Roles in science communication	10 min
	Pretest	15 min
II. Glyphosate	Lecture - What is glyphosate? - Which types of studies are used to investigate the cancerogenic potential of a chemical? - What are the roles of IARC and EFSA?	10 min
	Reading	25 min
	Posttest	15 min
III. Nature of Science	Discussion - Clearing comprehension difficulties - Discussion about aspects of nature of science	20 min
IV. Self-reflection	Interview - Self-reflection	30 min each

We decided to withhold the exact objective of the study from the students. They were only informed that the material was to be evaluated as part of a research study. The phrase "nature of science" or similar terms where never mentioned by the instructors. In this way, we wanted to prevent any potentially biasing the participants' responses. Furthermore, no specific reading instruction were given. This means, participants were not directed towards particular sections within the texts.

Instruments

To get a more detailed idea how modified articles can change the students' view on NOS, we used an explorative and qualitative approach to gather the data. By analyzing the students' responses, we aim to get more information which aspects of NOS are influenced by the text. By following a qualitative approach, we obtain more valuable details about participants' beliefs and are able to draw nuanced conclusions about the impact of APL. The used questionnaires were designed specifically for this study and contained questions similar to one of the most commonly used questionnaires *Views on Nature of Science Questionnaire* (VNOS) by Lederman et al. (2002).

Table 4. Asked questions of each phase. Question 2 and 3 of the pretest and question 3 of the posttest are adapted version of the VNOS-C questionnaire (N. G. Lederman et al., 2002), while the questions of the discussion and the interview are directly orientated to the consensus NOS aspects (N. G. Lederman, 2007). The questions are translated from German into English for this publication.

Phase		Questions
1. Pretest	1	Have you ever read primary scientific literature? Describe briefly what kind of primary literature you have read so far.
	2	Some substances, such as benzene, are classified as carcinogenic. How certain are scientists that these substances are carcinogenic? What specific evidence do you think scientists use to determine substances as carcinogenic?
	3	About 65 million years ago, the dinosaurs became extinct. The first of two popular hypotheses to explain the extinction suggests that a large meteorite hit the earth, which ultimately led to the extinction of the dinosaurs. The second hypothesis suggests that massive volcanic eruptions were responsible for the extinction. Explain how these different conclusions are possible when scientists have access to the same data and use it to support their conclusions?
2. Posttest	1	Write down questions about the text you would like to clarify in the group.
	2	Glyphosate has been assessed by the International Agency for Research on Cancer (IARC) as probably carcinogenic and by the European Food Safety Authority (EFSA) as probably non-carcinogenic. Explain in your own words how the different assessment resulted.
	3	Make a reasoned statement about the claim that the natural sciences and their methods always provide absolute evidence.
3. Discussion	1	Is scientific knowledge certain?
	2	Are scientists objective?
4. Interview	1	What have you learned?
	2	What did you learn about the certainty of scientific knowledge?
	3	What have you learned about the development of new knowledge?
	4	What did you learn about the scientific work method?

Before reading the ARA, the pretest was given, which was intended to determine prior experience of scientific literature (question 1) and prior knowledge about NOS (question 2 and 3). The two NOS questions were adapted from the VNOS-C questionnaire (N. G. Lederman et al., 2002) and refer to the classification of benzene as cancerogenic and the various hypotheses of dinosaur extinction, respectively. The posttest began by asking for unclear questions about the text (question 1). Subsequently, the participants were asked to give their own explanation about the different evaluations of glyphosate the involved agencies (question 2). This not only assessed text comprehension but also identified beliefs about the subjective or uncertain character of knowledge. In the last question (question 3), the participants were asked to express their position on the certainty of knowledge without a given context. The questions in the second half are designed to stimulate the group discussion and the self-reflection by the participants and are based on the consensus NOS aspects by Lederman (2007). The exact questions can be found in **Table 4.**

Data analysis

The intervention took place in July 2021. There were 21 students enrolled in the seminar, of which 14 were present during the intervention. Ten students uploaded pretest and posttest, but one student uploaded only a pretest and another uploaded only a posttest. Therefore, a total of eight participants submitted their documents at both data collection points. The voluntary post-seminar interview was conducted by six participants on a total of three separate sessions. Due to time constraints on the students' side, one interview was conducted with one participant (duration: 28 min), one with three participants (34 min), and the last with two participants (18 min). The seminar itself spanned a total of 166 min.

In order to perform an analysis, the obtained material underwent several processing steps. Initially, the recording was transcribed, followed by pseudonymization of the student's contributions. The transcripts of the seminar and the three interviews contain a total of 20,324 words (in German), so the resulting amount of data was very high. Subsequently, a summarizing inductive categorization was performed. Given that questions could not be exclusively assigned to defined aspects of NOS due to their multifaceted nature (N. G. Lederman et al., 2002), a deductive categorization was not feasible. Therefore, it is not possible to use a deductive categorization.

The categorization was based on the method of summarizing content analysis ("zusammenfassende Inhaltsanalyse") by Mayring (2015). The overarching objective of this analysis is to abstract the material in a reasonable way through generalization. For this purpose, the individual statements are first divided into units of analysis, which are then paraphrased individually. Paraphrases with the same meaning are eliminated, while all others are grouped into overarching categories. Meaning-related categorizations are then bundled. In **Table 5** we provide an example analysis of a response to question 3 in the pretest. Categories that were too specific and did not relate to any aspect of NOS were excluded from the analysis, e.g., the category "investigation of the historical atmosphere composition" from question 3 of the pretest, which included responses with specific technical content about ice core drilling in Antarctica and sediment formation. However, this does not lead to an exclusion of the entire answer, but only to partial aspects. If, for instance, the uncertainty of scientific knowledge was explained in the further course of the answer with the help of these examples, this was categorized accordingly.

Table 5. Example answer to question 3 of the pretest (see **Table 4**) and its analysis. The answer and its categorization are translated from German for this publication. The grouped categories are presented in the results.

Example answer	1: Division into analysis units	2: Paraphrasing	3 and 4: Grouping of categories
When scientists have a hypothesis, they try to prove it. On the one hand, they may interpret the data in a way that fits their hypothesis. Or perhaps the data is simply not accurate enough to give a clear answer and so they are interpreted in different ways.	When scientists have a hypothesis, they try to prove it.	Hypotheses are proven	Scientific methodology
	On the one hand, they may interpret the data in a way that fits their hypothesis.	Interpretation matching the hypothesis	Scientists are biased
	Or perhaps the data are simply not accurate enough to give a clear answer…	Data too poor for conclusion	Available data is inaccurate, insufficient and/or approximate
	… and so they are interpreted in different ways.	Poor data can be interpreted ambiguously	

Results

Phase 1: Pretest

Approximately half of the participants reported in the pretest (question 1) that they had no previous experience with primary scientific literature. Those who already had experience mentioned thematic relevance to chemistry, chemistry education or the other subject of their respective degree program[2] and was used, for example, for homework or experiment protocols.

The second question of the pretest was divided into two questions, yielding answers. The answers can be divided into three categories titled certainty (3), methodology (7), and theoretical foundation (4; the number indicates the quantity of students who gave answers that fall into this category). Regarding the first of the two questions, it is noticeable that only three out of nine participants mentioned the certainty of the classification of a cancerogenic substance, although it was explicitly asked for. The three given answers concerning the (un)certainty varied hugely: One student explained that some degree of uncertainty remains with such claims ("Therefore, I assume that there is some remaining uncertainty in such declarations, but that the suspect is strong enough for the chemical to carry a warning label."[3]), while another one stated that scientists exhibit high certainty ("When a substance is definitely classified in this way, scientists are very sure."). The last participant explained that scientists maintain certainty until their theories are confirmed, enhanced or falsified ("Scientists are certain until their theories are confirmed, expanded, or disproved").

Almost all participants (7 out of 9) referred to methodological evidence for the carcinogenicity of substances, especially model experiments conducted on animals or cells. However, their responses did not go beyond naming methods or procedures or stating that some experiments are performed and relevant to human organism (e.g., "often animal testing is done"). In four answers, the evidence was related to a more theoretical foundation, e.g., the classification is based on experience or the chemical structure of a substance ("The compounds have certain structural features that are known to be carcinogenic"). One participant did not provide a response to question 2.

For the third question of the pretest, the participants had to explain why scientists might arrive to different conclusions in the example of the extinction of the dinosaurs. The categorization identified seven potential justifications for the disagreement (the number indicates the quantity of students who gave such a reason):

a) The interpretation of the data of this case allows several explanations (5).
b) In general, several explanations are possible for scientific phenomena (2).
c) The scientists are biased (2).
d) The available data is inaccurate, insufficient and/or approximate (3).
e) No direct observation of the event is possible (2).
f) The supporting evidence is too similar (3).
g) The scientist used different data analysis methods (1).

Although the first two justifications sound similar, they differ in so far as explanation a) explicitly refers to this context while explanation b) is generalized and decontextualized. Other found categories were not relevant for the analysis.

Phase 2: Posttest

The majority of participants had no questions regarding the text. Two students responded in the first question of the posttest that they didn't understand the difference between the active substance and the formulation of an herbicide. This question was also the only question asked after the reading exercise and answered by the instructor.

[2] In Germany, a person who is interested in becoming a teacher at secondary school (e.g., "Gymnasium") usually has to graduate from a special degree program that includes two subjects and their didactics as well as pedagogy. The subjects can be chosen freely (under certain conditions, which may vary in the 16 federal states) and represent the school subjects that will be taught later as in-service teacher.

[3] This and the following quotes have been edited and translated for readability.

The categorization of the responses to the second question resulted in four different categories, summarizing the cause of the disagreement between IARC and EFSA (the number indicates the quantity of students who gave such a reason):

a) Different selection of studies (9)
b) Different evaluation of the studies (9)
c) Different weighting of the studies (4)
d) Different overall aim of the agencies (2)

All participants agreed that the variance in assessments was primarily attributed to differences in study selection and evaluation. While most responses were of a general nature, some elaborated further and justified the response with specific references to the content of the article. For example, three participants highlighted the divergence in the assessment of the studies on the different evaluation of tumor incidence at high doses.

The last question yielded many different responses which were challenging to categorize. Due to the heterogeneity of the answers, numerous categories resulted, which, however, were often only used by one participant. In total, 16 categories were formed. Therefore, we present here only the most pertinent ten ones:

a) Explicit rejection of the claim (5)
b) Properties of theories, models, and hypotheses
    b1) Theories are true (1)
    b2) Theories make predictions and are judged by them (1)
    b3) Theories change over time (3)
    b4) Unlike in mathematics, several solutions are possible in natural science (1)
c) Influence on science
    c1) Mistakes (1)
    c2) Ethical and subjective beliefs (3)
    c3) The choice and the development of new methods (4)
d) Certainty
    d1) Evidence is not permanently valid (4)
    d2) Forming consensus through review and quantity (3)

The remaining 6 categories were not relevant for the analysis.

Phase 3: Discussion

During the discussion phase, a few students took leading role and dominated the conversation. The primary themes that emerged in the discussion were the certainty of scientific knowledge and the objectivity of scientists were in the focus of the discussion. Since the results at this point were very similar to those of the interviews, we refrain from providing a detailed description, and we refer to the respective section.

Phase 4: Interviews

As described earlier, three interviews took place with a total of 6 participants. The same set of four questions were asked in each interview (cf. Tab. 4) to allow for cross-interview categorization. Despite our targeted focus on specific aspects of NOS through these questions, the responses were quite diverse. The participants were very detailed in their answers and linked different aspects. As a result, we chose to categorize responses across questions. For the interviews in which more than one person was interviewed, the responses were only assigned to a category if they expressed themselves accordingly or explicitly agreed with a previous speaker. Categorization results show that participants reported significant learning experiences in areas related to the development of scientific knowledge, certainty of scientific knowledge, and objectivity and subjectivity. Three statements of different participants were very specific about pre-existing knowledge about glyphosate, the properties of theories and truth in science and are bundled in a "miscellaneous" category, which we will not discuss in the following. The responses presented below summarize the results of the self-reflection of the participants, i.e., what the participants consider to be new learning for themselves.

Numerous contributions emphasized aspects concerning the development of scientific knowledge and the methodologies of science. Several students gained a better understanding of how scientific studies operate, especially regarding data collection and interpretation. To illustrate, one student stated: "… so, what actually constitutes science, (…) how scientific work is done in the studies. How that was worked out by the various agencies. That's what I've learned now, through the article."

Participants recognized the importance of interpreting scientific results and discussed the formation of scientific consensus through discussions and evidence presentation within the scientific community. ("Before, it was not quite so clear to me – So actually knowledge emerges more or less through a consensus, doesn't it?"). According to the student, these points were all unknown before the study. In the context of the glyphosate disagreement, two participants thought that the different results originated from different evaluations or to coincidences (e.g., "different results of the studies is due to coincidence or different evaluating").

Three students explicitly addressed the certainty of scientific knowledge. All of them stated that they had learned that scientific results should not be regarded as absolutely certain. However, one participant emphasized that a lot of knowledge, such as content from school, already had an "Erfahrungswert" (experience value) and accordingly no longer needed to be questioned. Moreover, data are absolute and "exactly as one would measure them", but their interpretation is subject to uncertainty.

Many statements in the interviews addressed the subjectivity or objectivity of scientific knowledge and methods. Several participants realized the inherent subjectivity in interpreting acquired data, which was inevitably influenced by human perspectives. One student expressed: “I think I learned that results of different scientific studies can be interpreted differently and are also partly subjective. That was not at all clear to me before.”, while another summarized their learning process as following:

“And I think I've learned that it's all a matter of interpretation, especially when it comes to interpretation and that different motivations of studies are carried out differently in order to achieve certain results and that it's not as objective as one might think.”

However, participants still described methods and data as objective.

Detailed progression of views on NOS of two participants

To provide a detailed picture of participants' views of NOS before and after the intervention, we will describe the progression of these views using two participants as representative examples. For the sake of anonymity, we refer to them as student A and student B.

Student A

Prior to the intervention, student A exhibited views on NOS which can be described partly as naive and informed. When asked about the certainty of a classification of a substance as cancerogenic (question 2 of the pretest), student A acknowledged some degree of uncertainty, but the reason for suspicion was clear enough to justify such classifications. They explained this with the typical "possibly carcinogenic" statement that can appear in the safety data sheets of chemicals. This interpretation was limited to specific cases and did not extend to science as a whole. In response to question 3 of the pretest, student A stated that “interpreting empirically collected data sometimes allows for multiple possible interpretations.” However, they attributed this ambiguity to inadequate historical data and the need for data reconstruction due to the significant time gap between the event of the dinosaur extinction and today. In addition, student A drew an analogy to the wave-particle duality of electrons, where they noted that certain data supported the 'electron as a particle' perspective while other data supported the opposite view. Combined, student A showed some informed views on NOS, often tied to a specific context.

After the intervention, student A exhibited modest improvements in their views on NOS. They now argue that “science should be as empirical and objective as possible, but it is limited in its objectivity by human, technical and ethical factors” (question 3 of the posttest). They reference the different evaluations of study results in the glyphosate case as an example and argue further, that “even scientists are not free of confirmation bias or values that they subconsciously bring into research.” In addition, student A mentions the tentative nature of science by declaring that it is possible to refute scientific results in the future by developing new and more plausible models.

This development in student A’s understanding of NOS is corroborated by their self-evaluation during the interview. There, the student described learning about the different interpretations and weightings of results in science. Concerning the uncertainty of science, student A claims to had have pre-knowledge from their time in school, which they attributed to an extensive study of the historical development of the atomic theory and acid-base definitions in chemistry classes. In conclusion, student A’s views on NOS underwent subtle changes only on nuances after the intervention. A strong pre-knowledge could explain this little change. Nonetheless, after the intervention, student A demonstrated an enhanced ability to articulate their views in a more decontextualized manner.

Student B

Student B was very reserved and concise in answering the questions of the pre- and posttest, necessitating a more comprehensive evaluation through their interview responses. Unfortunately, they did not answer question 2 of the pretest the way we intended it. Instead, they described experiments conducted on organisms similar to humans to measure tumor development. The question on the uncertainty of scientist concerning the classification of substances remained unanswered. Responding to question 3 of the pretest, student B shows a partly naive view on the subjectivity of science, as they argue that theories can be perceived subjectively but maintained that the underlying data remained unaffected by subjectivity.

In both the posttest and in the interview, student B displayed a more nuanced understanding. They now distinguish between the different interpretation of different study results and the subjectivity of the results themselves. Unlike their pre-test response, student B acknowledged that identical results could be subject to varying interpretations. Moreover, student B now describes a gap between the ideal and the reality of science by highlighting the subjectivity of every action. Asked about leaning gains concerning the scientific work method, they responded:

“And I think I've learned that it's all a matter of interpretation, especially in the analysis [of research results] and that different motivations of studies are carried out differently in order to achieve certain results and that it's not as objective as one always thinks.”

Concerning the certainty, the student now describes scientific results more carefully: “Mostly the results are only indications or trends” and “studies cannot always provide evidence”. In summary, a proper comparison of the pre- and posttest result is challenging since the participant was very short in answer. However, their interview responses resulted in more insights, highlighting a shift in their perception of the subjectivity inherent in science and among scientists.

Discussion

The primary aim of our study was to assess the potential impact of ASL on students' beliefs regarding NOS. Therefore, we focused on the aspects of the certainty of scientific knowledge, the empirical nature of scientific knowledge and the subjectivity and objectivity of science and scientists. Our investigation involved a multi-faceted approach, beginning with an analysis of students' performance in the text comprehension task within the posttest. Subsequently, we compared and discussed the findings from the pretest, posttest, and self-report interviews individually for each of the aforementioned aspects of NOS

In the text comprehension task (question 2 of the posttest), we asked for the reasons of the disagreement between IARC and EFSA. Every student was able to identify the different selection and the different evaluation of studies by the agencies, while less than half of the participants reported a different weighting of studies. Two participants additionally pointed out that these differences could be attributed to distinct objectives of the agencies. The precise nature of these distinct objectives, however, remained somewhat unclear. It remains unclear what exactly was meant by the agencies' different objectives. Possibly it is aimed at the fact that the IARC assesses the carcinogenic potential of glyphosate and its formulations, while the EFSA only wants to assess the carcinogenic potential of the pure substance. Additionally, since only two students asked questions about the content, it is reasonable to conclude the students were able to understood the content of the text and had a high degree of text comprehension. Results from Braun and Nückles (2014), comparing the text comprehension of different types of scientific texts, support this conclusion.

Certainty of scientific knowledge

Among the three aspects under consideration, the aspect of the certainty of scientific knowledge was the less explicitly discussed but was to some extent indirectly reflected in the participants' response behavior. In the pretest, participants showed views on scientific certainty that could be described as overall uniformed. As already presented, 6 out of 9 participants did not comment at all on this topic, even though they were explicitly asked about it. This can mean both that the participants simply overlooked the question as well as that they cannot judge how certain scientists are in the case described in the question. Since we had given the participants plenty of time to answer the questions, we tend to suggest the latter explanation. Regardless, the three given answers of the second question of the pretest were divers and showed both a more informed as well as a more naive view (cf. section "Phase 1: Pretest").

In contrast, the posttest responses indicated a shift towards more informed views. This was particularly evident in the fact that theories and evidence were now characterized as subject to change and not permanently valid (category b3, section "Phase 2: Posttest"). This was confirmed by the three students who had reported about their learning process in the interview (cf. section "Phase 4: Interviews"). Additionally, five students explicitly rejected the claim that the natural sciences and their methods always provide absolute evidence (category a, section "Phase 2: Posttest"). Nevertheless, one participant exhibited a more uninformed view by expressing that theories are true (category b1, section "Phase 2: Posttest").), which is indicative of an uniformed view. In summary, there was a notable positive shift within this aspect from perceiving science and scientific knowledge as certain to recognizing its inherent uncertainty.

As outlined in section "Pre-service teachers' views about NOS and interventions for changing them", some authors describe a resistance to change regarding this NOS aspect (e.g., Mesci & Schwartz, 2017; Müller & Reiners, 2023), while others have been successful in improving pre-service teachers' views of a tentative NOS (Abd-El-Khalick & Akerson, 2009; e.g., Akerson et al., 2000). In their review on students' and teachers understanding of NOS, Cofré et al. (2019) conclude that the tentativeness of scientific knowledge is more challenging and less readily improved aspect. Because of the wide variety of methods used in the interventions conducted by the authors mentioned above, there is no obvious pattern that explains these disparities. In fact, Braun and Nückles (2014) report no changes in their participants' views on the certainty of scientific knowledge or the ambiguity of scientific data after reading scientific literature (including an APL article), which is contrary to our results. One explanation to this disparity could lie in the specific content of the articles employed. While their articles centered on the tool behavior of the New Caledonian crow, our study utilized a review article addressing the scientific discord surrounding the potential carcinogenicity of glyphosate. These contexts are hardly comparable, which leads to the question, if certain contexts are more likely to change the view on the tentative NOS than other. Nevertheless, our findings lead us to conclude, that even such a brief intervention like reading adapted scientific literature can indeed foster improvements in perspectives concerning the tentative NOS.

Empirical nature of scientific knowledge

According to Lederman et al. (2002), the empirical nature of scientific knowledge signifies that science is based, at least in some part, on observations of the natural world. These observations are always "interpreted from within elaborate theoretical frameworks" (p. 499). The distinction between observation and inference is inherent in this aspect.

In the pretest, participants' responses demonstrated a wide range of perspectives. From the answers to the second question, hardly any NOS aspects regarding the empirical nature or the theory-laden nature of scientific knowledge could be identified, since the participants answered the question mainly on a technical level. This was evident from the naming of methods or procedures to study the carcinogenicity of a substance by the participants (cf. section "Phase 1: Pretest"). This changed for the third question, were approx. half of the students stated, that the interpretation of the data allows several explanations, which implies a difference between an observation and its interpretation (categories a and b, section "Phase 1: Pretest"). The two students who replied that no direct observation is possible and therefore scientists can only assume what happened (category e, section "Phase 1: Pretest"), showed a more naive understanding of NOS.

When asked for a reasoned statement about the claim that the natural sciences and their methods always provide absolute evidence (question 3 of the posttest), participants made statements primarily about the certainty of science. However, sometimes other aspects could be derived from the justifications, such as about the properties of scientific entities. One participant explained that theories make predictions and scientists judge them by these (category b2, section "Phase 2: Posttest"), while another explained that in science, unlike mathematics, multiple solutions to a problem are possible (category b4, section "Phase 2: Posttest"). The self-reports in the interviews provide more information about a change in views of the empirical nature of scientific knowledge. Although the answers were rather superficial, a learning effect with regard to scientific studies was described, i.e., how data are collected and interpreted (cf. section "Phase 4: Interviews"). Consequently, we conclude that no reliable change was found since participants exhibited a solid comprehension prior to engaging with the adapted article. Only some individual students showed a more informed behavior.

This conclusion is in line with most of the existing literature. Cofré et al. summarize that "the understanding of the empirical aspect is the most informed at the beginning of interventions, so it is difficult to substantial increase this level of understanding by the end of the interventions" (2019, p. 237). This finding is not exclusive to pre-service teachers, but is also true for in-service teachers (e.g., Demirel et al., 2023). Similar to von Hoff et al.'s (2019) observations, participants primarily reported learning effects regarding the empirical NOS on a technical and concrete level. It is plausible, that without further discussions, the readers are struggling to decontextualize the ideas concerning this NOS aspect. Reflecting on how a scientific article is written, e.g., why there is a distinction between results and discussion, could enforce a change of beliefs and make the inherent NOS aspects of written science communication transparent.

Subjectivity and objectivity of science and scientists

Various aspects, including the distinction between observation and conclusion as well as the social and cultural embeddedness of science play a pivotal role in the aspect of subjectivity or objectivity of science and scientist, as described in the theoretical framework (cf. section "Subjectivity and objectivity of science and scientists"). For this aspect, we specifically analyzed responses that explicitly referring to subjectivity or objectivity. Unfortunately, this was hardly addressed in the pretest, which is why a comparison with the posttest is difficult at this point. Regarding the different theories about the extinction of the dinosaurs, two participants in the pretest mentioned a possible bias of the scientists involved as a contributing factor (category c, section "Phase 1: Pretest"), indicative of a more informed view.

This trend can be confirmed in the posttest, where now three participants indicated that ethical and subjective beliefs have an influence on science (category c2, section "Phase 2: Posttest"). Notably, two of these participants had not expressed similar sentiments in the pretest. The statements are more detailed and of a higher quality than in the pretest. As described, many participants reported that they now realized that conclusions from data are inevitably influenced by subjectivity due to the inherent presence of human factors (cf. section "Phase 4: Interviews"). Overall, besides of the two mentioned participants, it is not possible to say whether views about the subjectivity and objectivity of science and scientists have changed because of the intervention, although there are tendencies in that direction. Based on the positive responses recorded during the interviews, we assume that an improved questioning in the pretest and posttest, a change might be more readily detectable.

Content of our adapted article was a scientific disagreement, which is paradigmatic for subjectivity. This was also done similarly by Ju et al. (2023), who used the Boyle-Hobbes debate on the existence of a vacuum in an air pump from the 17th century as the foundation for a chemistry education course for pre-service teacher. Their primary result was a positive change in the category of social-institutional aspects, but they also describe a significant change to an informed view on the subjectivity of science. Hamza et al. (2023) used authentic sources to explore the scientific disagreement on health effects of the Fukushima nuclear disaster and analyzed groups of students discussing these. In this study, the authors observed a general acceptance of scientific disagreements, which was closely associated with a more informed perspective on the tentative and subjective NOS Interestingly, the students found it difficult to cope with the disagreement.

Similar to the discussion of the results on the certainty of scientific knowledge, the content of the article seems to play a pivotal role in targeting specific NOS aspects. With our article, we have not only addressed a scientific controversy, but also a contemporary case, to which Allchin et al. (2014) attributes promising potential for promoting aspects such as uncertainty, tentativeness and subjectivity. Given these results, it is unclear whether the content or the structure of the adapted article was responsible for the change in participants' views of NOS.

Limitations and Conclusions

The results of our study indicate that after engaging with the employed adapted scientific article, an improvement in understanding about the certainty of scientific knowledge and the subjectivity or objectivity of science and scientists is possible. Although pre-existing knowledge impaired measurable improvements in the perception of the empirical nature of scientific knowledge, our findings offer promising perspectives for NOS education. However, some limitations have to be acknowledged.

A generalization of our results is not possible without further research. The two major limitations of our research are the small sample size and the specificity of the used text. An explanatory text about the same content could have similar effects on students as the ARA. However, due to our setting, it was not possible to use a comparable control group that would allow this verification. To address these limitations, future research should explore the effects of ASL using diverse texts and larger participant groups. In their experimental study, Braun and Nückles (2014) found a significant improvement in understanding of the constructive nature of science and the argumentative nature of science when reading research articles or a modified version of a research article in control to reading a popular scientific article and a chapter from a science textbook. Although they used a different text and examined other NOS aspects, Braun and Nückles indicate that the format of authentic scientific texts like research articles or APL have the potential to promote NOS understanding. As described in our theoretical framework, this can also be derived theoretically. With our different approach, we were able to support this claim.

The conducted interviews in our study could be affected by the social desirability bias in two ways: The participants could answer in a way they think it will be viewed favorably (1) by the interviewer or (2) by their peers for those who attended a group interview. Some arguments speak against these effects. The open-ended nature of our interview questions made it difficult to predict what would be considered a "positive" response by the interviewer, reducing the likelihood of bias toward instructors. Also, the instructors never mentioned the term NOS. The second bias in favor for the peers is not as easy to reject. A participant responding after another participant could be influenced by their response.

Many interventions aimed at pre-service teachers are relatively long-term, lasting one semester or more, and employ a mix of contextualized and decontextualized strategies to foster NOS understanding (Cofré et al., 2019) (cf. section "Pre-service teachers' views about NOS and interventions for changing them"). Since our intervention was very short compared to this, our presented finding of an improved NOS understanding is very promising for the use of ASL in education. Like Braun and Nückles (2014) describe, literature suggests that "beneficial effects of text-based instructional interventions unfold over the course of several lessons" (p. 898). Considering this, the theoretically derived connection between the characteristics of science communication and NOS (cf. section "Characteristics of (adapted) scientific literature and its educational potential"), previous findings on reading scientific literature (cf. section "Empirical research findings about reading APL in education"), as well as our discussed results, we argue that an extended course containing multiple readings of adapted articles can change the readers' view on NOS even better.

Expanding the intervention beyond simply reading the text to a task-based, active engagement with the text, would probably increase the impact on understanding of the NOS aspects. Prior research indicates that an explicit, reflective, and contextualized approach is more effective in fostering NOS comprehension (Abd-El-Khalick & Lederman, 2000; Bugingo et al., 2022; Khishfe, 2022). Exercises or prompts that draw students' attention to the argumentative structure of the text or to hedging could encourage reflection on NOS. Recent research by Hagen et al. (2023) supports the potential benefits of prompts before reading adapted primary literature. While participants who received prompting showed better text comprehension, interestingly, they did not differ from the control group on two dimensions of epistemological beliefs (certainty, source of knowledge). Only in one dimension (justification of knowledge), the group without prompting showed a more elaborated understanding, which the authors attribute to the expertise reversal effect. This demonstrates that more research is needed to determine optimal prompts for promoting epistemological beliefs or NOS.

It is open for question how much the used context effects the learning outcome. Using the open-ended question of the possible cancerogenic potential of glyphosate, the used adapted article explores the reason of the scientific disagreement between IARC and EFSA. Furthermore, the context has the potential to be used as a socio-scientific issue (SSI), which was not perceived by us. Enriching the intervention with strategies targeting the participants argumentation and reflection skills could also impact their views on NOS. Interestingly, research from Eastwood et al. (2012) suggests that SSI contexts could be effective for promoting NOS, while Khishfe and Lederman (2006) observed no difference in the improvements of their participants views between contextualized or decontextualized instructions. Results from Sadler et al. (2004) indicate a positive influence of NOS on handling conflicting evidence in an SSI. Future research has to explore the influence of the context of an adapted article on improving NOS views.

In addition, we propose that with a refined study design it would be possible and beneficial to investigate the exact connection between a research article and changing views on NOS. This would support the theoretical link between specific textual characteristics and NOS aspects. Based on our results, we believe that these inherent NOS aspects only impact the readers beliefs, if they are reflected. For example, as described in the theoretical framework, we linked the linguistic feature of hedging to the uncertainty of scientific knowledge and hypothesized that reading a scientific article would change this view (Hyland, 1998). However, research by Low (1996), Hyland (2000) and Takimoto (2015) suggest that hedging could be lexically invisible for high-school and university students, although the studies from Hyland and Takimoto are of limited comparability since they asked non-native speaker to judge an academic text in English language. This would mean that hedging would have to be more clearly reflected by instruction to have an effect on the tentative NOS. In contrast, other studies comparing texts with and without hedging show that hedging can influence readers, e.g., their attitude towards the presented content (Crismore & Vande Kopple, 1997a, 1997b) or the perception of trustworthiness (Jensen, 2008). Thus, it is reasonable to assume that NOS beliefs are also affected by hedging or other text features and the impact can be increased by pointing out these features.

Our study can only be understood as a first small step, and we encourage everyone to further explore the relationship between ASL with its unique characteristics and NOS. While our findings hold promises for NOS education, some questions remain unanswered. Is it possible to make the linkage between NOS and textual characteristics explicit, e.g., by prompting? Can reading ASL improve the views on other NOS aspects, too? Do different contexts lead to different results? Furthermore, it would be interesting to evaluate more complex strategies and integrate ASL in extended interventions, e.g., in combination with decision-making processes and SSIs or in an extended curriculum on the social aspects of science (NOSIS). Since publishing research is a central social aspect of the scientific community and reflects scientific values (Fang, 2005), we believe that it would be an excellent opportunity to use scientific literature for highlighting NOS.

In conclusion, we established a theoretical linkage between structural and linguistical characteristics of scientific articles and NOS and demonstrated that the use of ASL in educational settings is capable of improving readers' view on selected NOS aspects. While the exact expression of structural and linguistic properties of ASL is the focus of current investigations, these results will pave the way for innovative interventions in fostering NOS beliefs.

Concluding Summary

In this article, we have derived the potential of authentic scientific literature for NOS education. These texts, characterized by their unique organizational structure, rhetorical techniques like hedging, and references to other articles, inherently address critical NOS aspects like uncertainty, empirical foundations, the distinction between observations and conclusions, subjectivity, and the social nature of science.

Our qualitative study provides evidence that reading an adapted review article can effectively foster NOS understanding, aligning with Braun and Nückles' (2014) findings. Particularly our intervention demonstrated a notable impact on the comprehension of scientific knowledge certainty. We hypothesize that with a more focused question design, other NOS aspects such as the subjectivity of scientists might also be detectable. Furthermore, employing tailored prompts, as suggested by Hagen et al. (2023), holds promise for further enhancing the effectiveness of such interventions.

List of abbreviations

APL	Adapted primary literature
ARA	Adapted review articles
ASL	Adapted scientific literature
bw	body weight
ECHA	European Chemicals Agency
EFSA	European Food Safety Authority
EU	European Union
FRA	Family resemblance approach
FOS	Features of science
IARC	International Agency for Research on Cancer
IMRaD	Introduction, Methods, Results, and Discussion
JMPR	Joint FAO/WHO Meeting on Pesticide Residues
MTD	Maximum tolerable dose
NOS	Nature of science
NOSI	Nature of scientific inquiry
NOSIS	Nature of science in society
NOSK	Nature of scientific knowledge
SSI	Socio-scientific issues
VNOS	Views on Nature of Science Questionnaire

References

Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers' views and instructional planning. *International Journal of Science Education*, *27*(1), 15–42. https://doi.org/10.1080/09500690410001673810

Abd-El-Khalick, F., & Akerson, V. L. (2009). The influence of metacognitive training on preservice elementary teachers' conceptions of nature of science. *International Journal of Science Education*, *31*(16), 2161–2184. https://doi.org/10.1080/09500690802563324

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37*(10), 1057–1095. https://doi.org/10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417–436. https://doi.org/10.1002/(SICI)1098-237X(199807)82:4<417::AID-SCE1>3.0.CO;2-E

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching*, *37*(4), 295–317. https://doi.org/10.1002/(SICI)1098-2736(200004)37:4<295::AID-TEA2>3.0.CO;2-2

Allchin, D. (2003). Scientific myth-conceptions. *Science Education*, *87*(3), 329–351. https://doi.org/10.1002/sce.10055

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education*, *95*(3), 518–542. https://doi.org/10.1002/sce.20432

Allchin, D. (2012). Toward clarity on Whole Science and KNOWS. *Science Education*, *96*(4), 693–700. https://doi.org/10.1002/sce.21017

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education*, *98*(3), 461–486. https://doi.org/10.1002/sce.21111

Ariely, M., Livnat, Z., & Yarden, A. (2019). Analyzing the language of an adapted primary literature Article. Towards a disciplinary approach of science teaching using texts. *Science & Education*, *28*(1–2), 63–85. https://doi.org/10.1007/s11191-019-00033-5

Atanassova, I., Rey, F.-C., & Bertin, M. (2018). Studying uncertainty in science: A distributional analysis through the IMRaD structure. In European Language Resources Association (Ed.), *Proceedings of the Eleventh International Conference on Language Resources and Evaluation (LREC 2018).* Paris. http://lrec-conf.org/workshops/lrec2018/W24/summaries/10_W24.html

Atkinson, D. (1999). *Scientific discourse in sociohistorical context: The philosophical transactions of the Royal Society of London, 1675—1975.* Erlbaum.

Aljets, H. & Waitz, T. (2023). About the Potential of Adapted Scientific Literature for Science Education. In Pixel (Ed.), Conference Proceedings. New Perspectives in Science Education: 12th Conference Edition (pp. 216–219). Filodiritto Publisher.

Azninda, H., Raharjo, & Sunarti, T. (2021). Teachers' views about nature of science (NOS) using reconceptualised family resemblance approach to nature of science (RFN) questionnaire. *Journal of Physics: Conference Series*, *1747*(1), Article 012019. https://doi.org/10.1088/1742-6596/1747/1/012019

Barak, M. (2023). Family resemblance approach in science education. *Science & Education*, *32*(5), 1221–1225. https://doi.org/10.1007/s11191-023-00456-1

Baram-Tsabari, A., & Yarden, A. (2005). Text genre as a factor in the formation of scientific literacy. *Journal of Research in Science Teaching*, *42*(4), 403–428. https://doi.org/10.1002/tea.20063

Bazerman, C. (1985). Physicists reading physics. *Written Communication*, *2*(1), 3–23. https://doi.org/10.1177/0741088385002001001

Bell, R. L. (2006). Perusing Pandora's box: Exploring the what, when, and how of nature of science instruction. In L. B. Flick, & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 427–446). Springer. https://doi.org/10.1007/978-1-4020-5814-1_19

Bertin, M., Atanassova, I., Gingras, Y., & Larivière, V. (2016). The invariant distribution of references in scientific articles. *Journal of the Association for Information Science and Technology*, *67*(1), 164–177. https://doi.org/10.1002/asi.23367

Braun, I., & Nückles, M. (2014). Scholarly holds lead over popular and instructional: Text type influences epistemological reading outcomes. *Science Education*, *98*(5), 867–904. https://doi.org/10.1002/sce.21117

Brill, G., & Yarden, A. (2003). Learning biology through research papers: A stimulus for question-asking by high-school students. *Cell Biology Education*, *2*(4), 266–274. https://doi.org/10.1187/cbe.02-12-0062

Briones, R., Weichbrodt, C., Paltrinieri, L., Mey, I., Villinger, S., Giller, K., Lange, A., Zweckstetter, M., Griesinger, C., Becker, S., Steinem, C., & de Groot, B. L. (2016). Voltage dependence of conformational dynamics and subconducting states of VDAC-1. *Biophysical Journal*, *111*(6), 1223–1234. https://doi.org/10.1016/j.bpj.2016.08.007

Bugingo, J. B., Yadav, L. L., Mugisha, I. S., & Mashood, K. K. (2022). Improving teachers' and students' views on nature of science through active instructional approaches: A review of the literature. *Science & Education*, 33, 29–71. https://doi.org/10.1007/s11191-022-00382-8

Chappell, J., & Kacelnik, A. (2004). Selection of tool diameter by New Caledonian crows Corvus moneduloides. *Animal Cognition*, *7*(2), 121–127. https://doi.org/10.1007/s10071-003-0202-y

Cheung, K. K. C., & Erduran, S. (2023). A systematic review of research on family resemblance approach to nature of science in science education. *Science & Education*, *32*(5), 1637–1673. https://doi.org/10.1007/s11191-022-00379-3

Clough, M. P. (2007). Teaching the nature of science to secondary and post-secondary students: Questions rather than tenets. *The Pantaneto Forum*, *25*. http://pantaneto.co.uk/teaching-the-nature-of-science-to-secondary-and-post-secondary-students-questions-rather-than-tenets-michael-clough/

Cobern, W. W. (2020). Are we accidentally teaching students to mistrust science? *Journal of Research in Science, Mathematics and Technology Education*, *3*(1), 1–2.

Cofré, H., Núñez, P., Santibáñez, D., Pavez, J. M., Valencia, M., & Vergara, C. (2019). A critical review of students' and teachers' understandings of nature of science. *Science & Education*, *28*(3), 205–248. https://doi.org/10.1007/s11191-019-00051-3

Crismore, A., & Vande Kopple, W. J. V. (1997a). Hedges and readers: Effects on attitudes and learning. In *Hedging and Discourse* (pp. 83–114). de Gruyter. https://doi.org/10.1515/9783110807332.83

Crismore, A., & Vande Kopple, W. J. V. (1997b). The effects of hedges and gender on the attitudes of readers in the United States toward material in a science textbook. In *Culture and Styles of Academic Discourse* (pp. 223–247). de Gruyter. https://doi.org/10.1515/9783110821048.223

Dagher, Z. R., & Erduran, S. (2016). Reconceptualizing the nature of science for science education. *Science & Education*, *25*(1–2), 147–164. https://doi.org/10.1007/s11191-015-9800-8

Dagher, Z. R., & Erduran, S. (2023). To FRA or not to FRA: What is the question for science education? *Science & Education*, *32*(5), 1247–1264. https://doi.org/10.1007/s11191-023-00425-8

Davoodi-Semiromi, A., Schreiber, M., Nalapalli, S., Verma, D., Singh, N. D., Banks, R. K., Chakrabarti, D., & Daniell, H. (2010). Chloroplast-derived vaccine antigens confer dual immunity against cholera and malaria by oral or injectable delivery. *Plant Biotechnology Journal*, *8*(2), 223–242. https://doi.org/10.1111/j.1467-7652.2009.00479.x

Day, R. A. (1989). The origins of the scientific paper: The IMRAD format. *American Medical Writers Association Journal*, *4*(2), 16–18.

Demirel, Z. M., Sungur, S., & Çakıroğlu, J. (2023). Science teachers' views on the nature of science and its integration into instruction. *Science & Education*, *32*(5), 1401–1433. https://doi.org/10.1007/s11191-022-00409-0

Deng, F., Chen, D.-T., Tsai, C.-C., & Chai, C. S. (2011). Students' views of the nature of science: A critical review of research. *Science Education*, *95*(6), 961–999. https://doi.org/10.1002/sce.20460

Dimopoulos, K., & Karamanidou, C. (2013). Towards a more epistemologically valid image of school science: Revealing the textuality of school science textbooks. In M. S. Khine (Ed.), *Critical analysis of science textbooks: Evaluating instructional effectiveness* (1st ed., pp. 61–77). Springer. https://doi.org/10.1007/978-94-007-4168-3_4

Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International Journal of Science Education*, *34*(15), 2289–2315. https://doi.org/10.1080/09500693.2012.667582

Erduran, S., Dagher, Z. R., & McDonald, C. V. (2019). Contributions of the family resemblance approach to nature of science in science education. *Science & Education*, *28*(3), 311–328. https://doi.org/10.1007/s11191-019-00052-2

European Chemicals Agency (ECHA). (2022). *Glyphosate: No change proposed to hazard classification* [Press release]. Helsinki. https://echa.europa.eu/en/-/glyphosate-no-change-proposed-to-hazard-classification

European Commission. (2023). *No qualified majority reached by Member States* [Press release]. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/statement_23_5792

European Food Safety Authority (EFSA). (2015). Conclusion on the peer review of the pesticide risk assessment of the active substance glyphosate. *EFSA Journal*, *13*(11), Article 4302. https://doi.org/10.2903/j.efsa.2015.4302

European Food Safety Authority (EFSA). (2023). *Glyphosate: No critical areas of concern; data gaps identified* [Press release]. Parma. https://www.efsa.europa.eu/en/news/glyphosate-no-critical-areas-concern-data-gaps-identified

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education*, *30*(14), 1841–1866. https://doi.org/10.1080/09500690701579553

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education*, *89*(2), 335–347. https://doi.org/10.1002/sce.20050

Fernández, N., Benitez, F., & Romero-Maltrana, D. (2022). Social character of science and its connection to epistemic reliability. *Science & Education*, *31*(6), 1429–1448. https://doi.org/10.1007/s11191-021-00290-3

Fricke, K., & Reinisch, B. (2023). Evaluation of nature of science representations in biology school textbooks based on a differentiated family resemblance approach. *Science & Education*, *32*(5), 1583–1611. https://doi.org/10.1007/s11191-023-00444-5

Galili, I. (2019). Towards a refined depiction of nature of science. *Science & Education*, *28*(3–5), 503–537. https://doi.org/10.1007/s11191-019-00042-4

Goldman, S. R., & Bisanz, G. L. (2002). Toward a functional analysis of scientific genres: Implications for understanding and learning processes. In J. Otero, J. A. León, & A. C. Graesser (Eds.), *The psychology of science text comprehension* (1st ed., pp. 19–50). Erlbaum.

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Guyton, K. Z., Loomis, D., Grosse, Y., El Ghissassi, F., Benbrahim-Tallaa, L., Guha, N., Scoccianti, C., Mattock, H., & Straif, K. (2015). Carcinogenicity of tetrachlorvinphos, parathion, malathion, diazinon, and glyphosate. *The Lancet Oncology*, *16*(5), 490–491. https://doi.org/10.1016/S1470-2045(15)70134-8

Hagen, R. (2023). *Adaptierte Primärliteratur in der Hochschule—Einfluss auf Textverständnis und epistemologische Überzeugungen von Studierenden im ersten Studienabschnitt* [Adapted primary literature in higher education—Influence on text comprehension and epistemological beliefs of students in the first year of study] [Dissertation, Freie Universität Berlin]. https://doi.org/10.17169/refubium-37542

Hagen, R., Watermann, R., & Nückles, M. (2022). Der Einfluss wissenschaftlicher Textgenres auf das Textverständnis und epistemologische Überzeugungen bei Studierenden der Bildungswissenschaften [The influence of scientific text genres on text comprehension and epistemological beliefs among students of educational sciences]. *Swiss Journal of Educational Research*, *44*(2), 237–249. https://doi.org/10.24452/sjer.44.2.6

Hagen, R., Watermann, R., & Nückles, M. (2023). *Adapted primary literature among first-year students: Effects on text comprehension and epistemological beliefs*. Manuscript.

Hamza, K., Wojcik, A., Arvanitis, L., Haglund, K., Lundegård, I., & Schenk, L. (2023). Nature of science in students' discussions on disagreement between scientists following a narrative about health effects of the Fukushima Daiichi accident. *International Journal of Science Education*, *45*(1), 22–42. https://doi.org/10.1080/09500693.2022.2151327

Harmon, J. E. (1989). The structure of scientific and engineering papers: A historical perspective. *IEEE Transactions on Professional Communication*, *32*(3), 132–138. https://doi.org/10.1109/47.31618

Harmon, J. E. (1992). Current contents of theoretical scientific papers. *Journal of Technical Writing and Communication*, *22*(4), 357–375. https://doi.org/10.2190/V051-8UKA-W8FJ-U54N

Harré, R. (1990). Some narrative conventions of scientific discourse. In C. Nash (Ed.), *Narrative in culture: The uses of storytelling in the sciences, philosophy, and literature* (pp. 83–102). Routledge.

Hill, S. S., Soppelsa, B. F., & West, G. K. (1982). Teaching ESL students to read and write experimental-research papers. *TESOL Quarterly*, *16*(3), 333–347. https://doi.org/10.2307/3586633

Hodson, D. (2014). Nature of science in the science curriculum: Origin, development, implications and shifting emphases. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 911–970). Springer. https://doi.org/10.1007/978-94-007-7654-8_28

Hoff, E. v., Aljets, H., Milsch, N., Waitz, T. & Mey, I. (2019). Working with Adapted Primary Literature in Chemistry Class. CHEMKON, 26(5), 190–193. https://doi.org/10.1002/ckon.201800070

Hoskins, S. G., Lopatto, D., & Stevens, L. M. (2011). The C.R.E.A.T.E. approach to primary literature shifts undergraduates' self-assessed ability to read and analyze journal articles, attitudes about science, and epistemological beliefs. *CBE—Life Sciences Education*, *10*(4), 368–378. https://doi.org/10.1187/cbe.11-03-0027

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education*, *104*(4), 641–666. https://doi.org/10.1002/sce.21575

Hyland, K. (1994). Hedging in academic writing and EAF textbooks. *English for Specific Purposes*, *13*(3), 239–256. https://doi.org/10.1016/0889-4906(94)90004-3

Hyland, K. (1998). *Hedging in scientific research articles*. John Benjamins Publishing Company. https://doi.org/10.1075/pbns.54

Hyland, K. (2000). Hedges, boosters and lexical invisibility: Noticing modifiers in academic texts. *Language Awareness*, *9*(4), 179–197. https://doi.org/10.1080/09658410008667145

Hyland, K. (2010). Constructing proximity: Relating to readers in popular and professional science. *Journal of English for Academic Purposes*, *9*(2), 116–127. https://doi.org/10.1016/j.jeap.2010.02.003

International Agency for Research on Cancer (IARC). (2015). *Some organophosphate insecticides and herbicides*. International Agency for Research on Cancer.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, *20*(7), 591–607. https://doi.org/10.1007/s11191-010-9293-4

Irzik, G., & Nola, R. (2023). Revisiting the foundations of the family resemblance approach to nature of science: Some new ideas. *Science & Education*, *32*(5), 1227–1245. https://doi.org/10.1007/s11191-022-00375-7

Jefferson, T., Wager, E., & Davidoff, F. (2002). Measuring the quality of editorial peer review. *JAMA*, *287*(21), 2786–2790. https://doi.org/10.1001/jama.287.21.2786

Jensen, J. D. (2008). Scientific uncertainty in news coverage of cancer research: Effects of hedging on scientists' and journalists' credibility. *Human Communication Research*, *34*(3), 347–369. https://doi.org/10.1111/j.1468-2958.2008.00324.x

Ju, H., Cho, E. H., & Paik, S.-H. (2023). Impact of teaching materials based on the family resemblance approach on pre-service chemistry teachers' views of nature of science. *Asia-Pacific Science Education*, *9*(1), 194–225. https://doi.org/10.1163/23641177-bja10059

Kampourakis, K. (2016). The "general aspects" conceptualization as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching*, *53*(5), 667–682. https://doi.org/10.1002/tea.21305

Kararo, M., & McCartney, M. (2019). Annotated primary scientific literature: A pedagogical tool for undergraduate courses. *PLoS Biology*, *17*(1), Article 3000103. https://doi.org/10.1371/journal.pbio.3000103

Khishfe, R. (2022). Improving students' conceptions of nature of science: A review of the literature. *Science & Education*, *32*(6), 1887–1931. https://doi.org/10.1007/s11191-022-00390-8

Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching*, *43*(4), 395–418. https://doi.org/10.1002/tea.20137

Kostøl, K. B., Bøe, M. V., & Skår, A. R. (2023). Nature of science in Norway's recent curricula reform. *Science & Education*, *32*(5), 1561–1581. https://doi.org/10.1007/s11191-022-00399-z

Kronick, D. A. (1962). *A history of scientific and technical periodicals: The origins and development of the scientific and technological press 1665-1790*. Scarecrow Press.

Laslo, M., & Hartmann, M. (2023). Developing scientific communication skills using primary literature in an undergraduate cell biology course. *Journal of Microbiology & Biology Education*, *24*(2), Article e00186-22. https://doi.org/10.1128/jmbe.00186-22

Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Meyer, A. A., & Schwartz, R. S. (2014). Meaningful assessment of learners' understandings about scientific inquiry—The views about scientific inquiry (VASI) questionnaire. *Journal of Research in Science Teaching*, *51*(1), 65–83. https://doi.org/10.1002/tea.21125

Lederman, N. G. (2006). Syntax of nature of science within inquiry and science instruction. In L. B. Flick, & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 301–317). Springer. https://doi.org/10.1007/978-1-4020-5814-1_14

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell, & N. G. Lederman (Eds.), *Handbook of research on science education* (1st ed., pp. 831–880). Erlbaum.

Lederman, N. G., & Lederman, J. S. (2019). Teaching and learning nature of scientific knowledge: Is it Déjà vu all over again? *Disciplinary and Interdisciplinary Science Education Research*, *1*(6). https://doi.org/10.1186/s43031-019-0002-0

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*(6), 497–521. https://doi.org/10.1002/tea.10034

Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F., & Bell, R. L. (2001). Pre-service teachers' understanding and teaching of nature of science: An intervention study. *Canadian Journal of Science, Mathematics and Technology Education*, *1*(2), 135–160. https://doi.org/10.1080/14926150109556458

Lee, C. J., Sugimoto, C. R., Zhang, G., & Cronin, B. (2013). Bias in peer review. *Journal of the American Society for Information Science and Technology*, *64*(1), 2–17. https://doi.org/10.1002/asi.22784

Low, G. (1996). Intensifiers and hedges in questionnaire items and the Lexical Invisibility Hypothesis. *Applied Linguistics*, *17*(1), 1–37. https://doi.org/10.1093/applin/17.1.1

Matkins, J. J., & Bell, R. L. (2007). Awakening the scientist inside: Global climate change and the nature of science in an elementary science methods course. *Journal of Science Teacher Education*, *18*(2), 137–163. https://doi.org/10.1007/s10972-006-9033-4

Matthews, M. R. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in nature of science research* (pp. 3–26). Springer. https://doi.org/10.1007/978-94-007-2457-0_1

Mayring, P. (2015). *Qualitative Inhaltsanalyse: Grundlagen und Techniken* [Qualitative content analysis: Basics and techniques] (12th ed.). Beltz.

McCartney, M., Wan, X., Griep, C. D., & Lighthall, N. R. (2023). Primary scientific literature is not just for students and academics: A study of primary source modalities and predictors of learning across adulthood. *Journal of Microbiology & Biology Education*, *24*(1). https://doi.org/10.1128/jmbe.00122-22

McMahan, P., & McFarland, D. A. (2021). Creative destruction: The structural consequences of scientific curation. *American Sociological Review*, *86*(2), 341–376. https://doi.org/10.1177/0003122421996323

Meadows, A. J. (1985). The scientific paper as an archaeological artefact. *Journal of Information Science*, *11*(1), 27–30. https://doi.org/10.1177/016555158501100104

Meadows, A. J. (1998). *Communicating research*. Academic Press.

Mesci, G., & Schwartz, R. S. (2017). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education*, *47*(2), 329–351. https://doi.org/10.1007/s11165-015-9503-9

Mourez, M., Kane, R. S., Mogridge, J., Metallo, S., Deschatelets, P., Sellman, B. R., Whitesides, G. M., & Collier, R. J. (2001). Designing a polyvalent inhibitor of anthrax toxin. *Nature Biotechnology*, *19*(10), 958–961. https://doi.org/10.1038/nbt1001-958

Müller, S., & Reiners, C. S. (2023). Pre-service chemistry teachers' views about the tentative and durable nature of scientific knowledge. *Science & Education*, *32*, 1813–1845. https://doi.org/10.1007/s11191-022-00374-8

Myers, G. (1991). Stories and styles in two molecular biology review articles. In C. Bazerman, & J. G. Paradis (Eds.), *Textual dynamics of the professions: Historical and contemporary studies of writing in professional communities* (pp. 45–75). University of Wisconsin Press.

Myers, G. (1992). Textbooks and the sociology of scientific knowledge. *English for Specific Purposes*, *11*(1), 3–17. https://doi.org/10.1016/0889-4906(92)90003-S

Nicolaisen, J., & Frandsen, T. F. (2012). Consensus formation in science modeled by aggregated bibliographic coupling. *Journal of Informetrics*, *6*(2), 276–284. https://doi.org/10.1016/j.joi.2011.08.001

Norris, S. P., Stelnicki, N., & Vries, G. (2012). Teaching mathematical biology in high school using adapted primary literature. *Research in Science Education*, *42*(4), 633–649. https://doi.org/10.1007/s11165-011-9215-8

Okan, B., & Kaya, E. (2023). Exploring the inclusion of nature of science in Turkish middle school science textbooks. *Science & Education*, *32*(5), 1515–1535. https://doi.org/10.1007/s11191-022-00371-x

Osborne, J., & Pimentel, D. (2022). Science, misinformation, and the role of education. *Science*, *378*(6617), 246–248. https://doi.org/10.1126/science.abq8093

Ozgelen, S., Yilmaz-Tuzun, O., & Hanuscin, D. L. (2013). Exploring the development of preservice science teachers' views on the nature of science in inquiry-based laboratory instruction. *Research in Science Education*, *43*(4), 1551–1570. https://doi.org/10.1007/s11165-012-9321-2

Paré, G., Trudel, M.-C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management*, *52*(2), 183–199. https://doi.org/10.1016/j.im.2014.08.008

Pautasso, M. (2013). Ten simple rules for writing a literature review. *PLoS Computational Biology*, *9*(7), Article e1003149. https://doi.org/10.1371/journal.pcbi.1003149

Phillips, L. M., & Norris, S. P. (2009). Bridging the gap between the language of science and the language of school science through the use of adapted primary literature. *Research in Science Education*, *39*(3), 313–319. https://doi.org/10.1007/s11165-008-9111-z

Popper, K. R. (1963). *Conjectures and refutations: The growth of scientific knowledge*. Routledge and Paul.

Rawlings, J. S. (2019). Primary literature in the undergraduate immunology curriculum: Strategies, challenges, and opportunities. *Frontiers in Immunology*, *10*. https://doi.org/10.3389/fimmu.2019.01857

Regulation 2023/2660. *Commission Implementing Regulation (EU) 2023/2660 of 28 November 2023 renewing the approval of the active substance glyphosate in accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council and amending Commission Implementing Regulation (EU) No 540/2011*. http://data.europa.eu/eli/reg_impl/2023/2660/oj

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*, *26*(4), 387–409. https://doi.org/10.1080/0950069032000119456

Schmid, K. M., Dunk, R. D. P., & Wiles, J. R. (2021). Early exposure to primary literature and interactions with scientists influences novice students' views on the nature of science. *Journal of College Science Teaching*, *50*(6), 40–47. https://doi.org/10.1080/0047231X.2021.12290532

Seung, E., Bryan, L. A., & Butler, M. B. (2009). Improving preservice middle grades science teachers' understanding of the nature of science using three instructional approaches. *Journal of Science Teacher Education*, *20*(2), 157–177. https://doi.org/10.1007/s10972-009-9130-2

Shwed, U., & Bearman, P. S. (2010). The temporal structure of scientific consensus formation. *American Sociological Review*, *75*(6), 817–840. https://doi.org/10.1177/0003122410388488

Sinding, C. (1996). Literary genres and the construction of knowledge in biology: Semantic shifts and scientific change. *Social Studies of Science*, *26*(1), 43–70. https://doi.org/10.1177/030631296026001004

Sollaci, L. B., & Pereira, M. G. (2004). The introduction, methods, results, and discussion (IMRAD) structure: A fifty-year survey. *Journal of the Medical Library Association*, *92*(3), 364–367.

Suppe, F. (1998). The structure of a scientific paper. *Philosophy of Science*, *65*(3), 381–405. https://doi.org/10.1086/392651

Swales, J. (1990). *Genre analysis: English in academic and research settings* (1st ed.). Cambridge University Press.

Takimoto, M. (2015). Assertions and lexical invisibility in EFL learners' academic essays. *Journal of Pragmatics*, *89*, 85–99. https://doi.org/10.1016/j.pragma.2015.09.009

Tarazona, J. V., Court-Marques, D., Tiramani, M., Reich, H., Pfeil, R., Istace, F., & Crivellente, F. (2017). Glyphosate toxicity and carcinogenicity: A review of the scientific basis of the European Union assessment and its differences with IARC. *Archives of Toxicology*, *91*(8), 2723–2743. https://doi.org/10.1007/s00204-017-1962-5

Trautwein, U., Köller, O., & Baumert, J. (2001). Lieber oft als viel: Hausaufgaben und die Entwicklung von Leistung und Interesse im Mathematik-Unterricht der 7. Jahrgangsstufe [Better often than too much: Homework and the development of performance and interest in mathematics lessons in the 7th grade]. *Zeitschrift Für Pädagogik*, *47*(5), 703–724. https://doi.org/10.25656/01:4310

Voss, S., Kent-Schneider, I., Kruse, J., & Daemicke, R. (2023). Investigating the development of preservice science teachers' nature of science instructional views across rings of the family resemblance approach wheel. *Science & Education*, *32*(5), 1363–1399. https://doi.org/10.1007/s11191-023-00418-7

Wittgenstein, L. (1953). *Philosophische Untersuchungen* [Philosophical investigations]. Blackwell.

Wonham, M. J., de-Camino-Beck, T., & Lewis, M. A. (2004). An epidemiological model for West Nile virus: Invasion analysis and control applications. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *271*(1538), 501–507. https://doi.org/10.1098/rspb.2003.2608

Wu, J. (2011). Improving the writing of research papers: IMRAD and beyond. *Landscape Ecology*, *26*(10), 1345–1349. https://doi.org/10.1007/s10980-011-9674-3

Yarden, A., Brill, G., & Falk, H. (2001). Primary literature as a basis for a high-school biology curriculum. *Journal of Biological Education*, *35*(4), 190–195. https://doi.org/10.1080/00219266.2001.9655776

Yarden, A., Phillips, L. M., & Norris, S. P. (2015). *Adapted primary literature: The use of authentic scientific texts in secondary schools* (1st ed.). Springer. https://doi.org/10.1007/978-94-017-9759-7

Yeh, Y.-F., Dhurumraj, T., & Ramnarain, U. (2023). Representations of the nature of science in South African physical sciences textbooks on electricity and magnetism. *Science & Education*, *32*(5), 1537–1559. https://doi.org/10.1007/s11191-022-00370-y