



Nature of Science in Science Educational Videos

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Abstract

Students' understanding of the nature of science (NOS) is typically naïve. As such, it is important to introduce students explicitly and often to NOS in the classroom, but also in science educational videos, as students use these videos increasingly to study. However, it is unclear to what extent NOS is present in these videos. As such, this study examines the NOS in science educational videos on YouTube. Videos were selected for three content topics (mitosis, vaccines, and nucleosynthesis) and from periods before, during, and after the COVID-19 pandemic. The videos were transcribed and deductively coded for NOS based on Lederman's conceptualization of NOS. The results showed that NOS is typically not discussed in the videos, and when it is present, it is typically presented in a partially informed manner. Additionally, while COVID-19 did not significantly impact the overall inclusion of NOS, it did influence certain aspects. We suggest a more informed and explicit incorporation of NOS in educational videos to also introduce NOS to students (and other viewers) in informal and nonformal learning.

Keywords Informal learning · Nature of science · Science education · Scientific literacy · Educational video

1 Introduction

Scientific literacy is a goal of both science education and science communication, aiming to equip individuals with the necessary knowledge, decision-making capabilities, and critical thinking skills (Holbrook & Rannikmäe, 2007; Jurecki & Wander, 2012). A construct from science education literature, the nature of science (NOS), plays a crucial role in this regard.

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Several science education studies have repeatedly shown that pre- or in-service instructors, as well as students, often do not have a nuanced understanding of NOS (Cofré et al., 2019; Lederman, 2007). Moreover, NOS is infrequently—and often inadequately—represented in textbooks (Abd-El-Khalick et al., 2008; Li et al., 2022; Su et al., 2023), curricula, and assessment (Cheung, 2020), and international science education standards documents (Olson, 2018).

In science communication, NOS is considered important in enhancing scientific literacy (Van Dijk, 2011). Indeed, Reiß and McComas (2020) suggest that informal science education institutions should invest in communicating about NOS, allowing constructs from science education to find their way into science communication contexts, a bridge that is necessary according to Baram-Tsabari and Osborne (2015).

In the last decade, internet platforms have become the primary means of communicating science-related content (Brossard, 2013; Fähnrich et al., 2023), students are increasingly using science educational videos as a tool for learning, and educators are using videos to improve student engagement and attention retention (Barlis et al., 2023). These trends further developed during the COVID-19 pandemic, as educational institutions focused on using online educational resources and implementing remote learning methods (Madzimore, 2022; Riccaboni & Verginer, 2022).

However, to the best of the researchers' knowledge, no studies have been conducted on the representation of NOS in educational videos specifically. Therefore, the primary aim of this study is to investigate whether NOS aspects are present in science educational videos at all. A secondary aim is to explore whether the inclusion of NOS has changed across three periods: before, during, and after COVID-19. This temporal comparison is intended to assess whether the increased public interest in science during the pandemic was reflected in the way NOS was included or communicated. In doing so, the study seeks to identify possible changes in NOS inclusion over time and assess whether science communicators adjusted their content in reaction to COVID-19.

In order to accomplish this goal, this study will specifically examine educational videos on YouTube, which is widely recognized as a popular platform (Barlis et al., 2023). Our research lays the groundwork for understanding the current landscape of including NOS in science educational videos and offers a starting point for future investigations into how science is communicated through educational videos.

2 Literature Review

This section will examine the existing literature in three main areas relevant to the current study. First, we examine the concept of the nature of science (NOS). Secondly, we investigate the comprehension of NOS among students and educators. Lastly, we examine the usage of educational videos in (science) education. This literature establishes a basis for examining the inclusion of NOS in science educational videos and the temporal changes in its incorporation.

2.1 Nature of Science (NOS)

The NOS has been generally used to “refer to the epistemology of science, science as a way of knowing, or the values and beliefs inherent in the development of scientific knowledge” (Abd-El-Khalick et al., 1998, p. 418). While there are “disagreements that continue to exist

among philosophers, historians, and science educators [that] are far too abstract for K-12 students to understand and far too esoteric to be of immediate consequence to their daily lives” (Abd-El-Khalick et al., 1998, p. 418), there exists a level of generality regarding NOS that is both comprehensible to K-12 students, and thus, presumably also to the general public, and applicable to their everyday experiences. Lederman et al. (2002) further developed NOS into a framework consisting of the following seven aspects.

1. The difference between observation and inference: Understanding the difference between direct, sensory-based descriptions of natural phenomena and higher-order inferences and explanations (empirical NOS).
2. The difference between laws and theories: Laws pertain to relations between observational statements, while theories are inferred explanations for observable phenomena; there is no hierarchy between laws and theories (law and theory NOS).
3. Science is creative and innovative (creativity NOS).
4. Scientific knowledge is theory-laden (theory-laden NOS).
5. Science is part of human culture: It affects and is affected by non-scientific elements of the culture in which it is embedded (social and culture NOS).
6. Scientific knowledge is tentative (tentativeness NOS).
7. Science uses many different methods, there is no such thing as “the” scientific method (method NOS).

This list has been refined by other authors (e.g., Galili, 2019; McComas, 2007) as this is a field of active research (Bugingo et al., 2022). This list, though sometimes referred to as the ‘consensus view,’ is also challenged on a more fundamental level. For example, the Family Resemblance Approach (FRA) (Irzik & Nola, 2011) criticizes the NOS framework for portraying a narrow representation of science and neglecting discipline differences. FRA expands its scope by incorporating not only cognitive-epistemic aspects but also social-institutional aspects such as financial systems, institutional influences, and societal values. Still, we will make use of the most common conceptualization of NOS, as outlined above by Lederman et al. (2002). This is because this conceptualization of NOS is foundational, (still) frequently referenced, and often used (also outside of the academic literature, e.g., in the NGSS curriculum (McComas & Nouri, 2016)). Moreover, Schwartz and Lederman (2008) demonstrated that these seven categories of NOS are applicable to all science disciplines, regardless of the specific context. This suggests a high level of generalization, as NOS views do not appear to vary based on the field of science.

2.2 NOS in Education

Developing a nuanced understanding of the NOS has been advocated as an important goal for students studying science since the 1900s (Lederman, 2007). Using various standardized tools (e.g., View of Nature of Science (VNOS), Lederman et al., 2002), students’ and teachers’ conceptions of NOS were assessed. This research effort showed that students’ understanding of NOS was often naïve (Cofré et al., 2019), a result that seems to be consistent globally (e.g., Kang et al., 2005; Sormunen & Köksal, 2014; Van Griethuijsen et al., 2014). Moreover, teachers’ understanding seems to be, in general, naïve (Abd-El-Khalick & Lederman, 2000b; Cofré et al., 2019). This is worrisome, as teachers’ understanding directly influences their teaching methods in the classroom (e.g., Lantz & Kass, 1987; Lederman, 1992).

Several teaching approaches to introduce students to NOS have been researched. It seems that explicitly introducing NOS in the classroom is effective in improving students' and pre-, in-, service teachers' NOS conceptions (Akerson et al., 2005; García-Carmona, 2021; Lederman et al., 2013; Mesci & Schwartz, 2016). Indeed, Clough (2018) makes clear that students' attention must be overtly drawn to NOS ideas in a manner that requires them to mentally engage and wrestle with these issues. Moreover, integrating explicit instruction in NOS not only complements content learning but may also enhance knowledge retention among students. For example, Khishfe (2020) demonstrated that students who received explicit instruction in both argumentation skills and NOS concepts retained these skills and concepts better over time.

There are several approaches to introduce NOS explicitly (Cofré et al., 2014). For example, an intervention incorporating NOS into the history of science demonstrated an enhancement in the comprehension of NOS (Abd-El-Khalick & Lederman, 2000a; Kim & Irving, 2009). Other approaches that have been researched are, amongst others (McComas, 2020), using children's literature (Erumit & Akerson, 2021), philosophical dialogue (De Schrijver et al., 2016), or storytelling (Kapsala & Mavrikaki, 2020).

2.3 Usage of Media in (Science) Education

Educational videos are "aimed at introducing and explaining a certain topic of interest" (Bitzenbauer et al., 2023, p. 26), and numerous educational videos on different topics, such as science, technology, and society courses, are uploaded on various media platforms (Barlis et al., 2023). One of the most popular platforms is YouTube (Barlis et al., 2023; Mohamed & Shoufan, 2022). YouTube hosts a wide range of videos, including both entertaining content and educational videos contributed by individuals, professionals, organizations, and companies (Van Den Eynde et al., 2019). The videos are utilized by both the general public with specific interests (Bitzenbauer et al., 2023) and by students and teachers who are increasingly integrating them into formal education and classrooms (Mohamed & Shoufan, 2022).

Students utilize YouTube videos to seek information and enhance their academic learning, thereby enriching their learning activities and facilitating self-directed learning (Mohamed & Shoufan, 2022). For example, a study from Van Den Eynde et al. (2019) stated that medical students frequently utilize audiovisual materials on YouTube as a supplementary resource for their textbooks and academics. Therefore, it has become an integral component of students' information resources, frequently serving as a supplement to textbooks and academic courses (Tume, 2023).

In addition, teachers are utilizing educational videos to acquire knowledge from proficient instructors and to create their own explanatory videos for flipped classroom environments (Kulgemeyer, 2018). Indeed, educators and teachers have acknowledged the educational significance of YouTube and have utilized it for instructional objectives (Bitzenbauer et al., 2023).

There are, however, several challenges in using YouTube videos for (science-)education. The videos on the platform are not primarily created to cater to educational settings. Rather, YouTube is predominantly associated with entertainment (Davis et al., 2020). Many videos are designed to attract and maintain (the attention of) a broader audience on the platform. As such, video creators often customize their content to be concise and focused on singular, straightforward subjects to meet viewer preferences (Kohler & Dietrich, 2021). Given that videos can be monetized through advertisements, many videos also have other

incentives, often driven by the algorithm (Chu et al., 2022; Anderson, 2023). Furthermore, students may perceive the videos variably based on their prior knowledge, leading to disparate learning outcomes (Kohler & Dietrich, 2021). Lastly, not all videos conform to educational standards or curricula (Akgun et al., 2013). All of this combined underscores the necessity for teacher involvement in selecting and contextualizing the videos used in education (Mohamed & Shoufan, 2022).

Amidst the COVID-19 pandemic, YouTube emerged as a prominent platform for organizations and governments, owing to its characteristic as a social media platform that rapidly disseminates information (Pulido et al., 2020). They utilized YouTube to reform, enhance awareness, and swiftly communicate the dynamically evolving pandemic situation, including health interventions (Shahbazi et al., 2023). Approximately 80% of internet users rely on the internet to obtain health-related information (Srivastava & Raina, 2022; Wolynn et al., 2023), and a high percentage of inaccurate or misleading health information was circulating during the COVID-19 pandemic (Pulido et al., 2020; Shahbazi et al., 2023; Zhu et al., 2022).

For example, Parabhoi et al. (2021) reviewed four studies examining the proportion of health misinformation on social media and found that it reached up to 51% in posts associated with vaccines, up to 28.8% in posts associated with COVID-19, and up to 60% in posts related to pandemics.

In order to address this issue, numerous studies were undertaken. For example, Talabi et al. (2021) conducted an intervention that countered fake news about the COVID-19 vaccine. Zhu et al. (2022) conducted a study that utilized an altruism-eliciting video intervention to enhance the understanding of herd immunity. The World Health Organization (WHO) has established a dedicated section on its website to address misconceptions and refute false information, to offer the public trustworthy data (Pulido et al., 2020).

YouTube was also used more in education during the COVID-19 pandemic because of limited movement and lockdown. Remote and blended learning were necessary for educators and students to engage in education (Barlis et al., 2023).

Overall, COVID-19 has underscored the critical need for effective science communication and scientific literacy (Cheung et al., 2023; Fähnrich et al., 2021). Given the vast amount of scientific knowledge accessible, it became clear that there was an urgent requirement to promote public education regarding the science of vaccines (Smyth et al., 2023), as well as broader science education (Reiss, 2020).

3 Research Questions

Given that developing a nuanced understanding of the NOS is an accepted learning goal, that teachers and students typically have a naïve understanding, and that teachers and students increasingly turn to online science educational videos, the question arises as to what extent NOS is incorporated into online science educational content. Moreover, given the impact of the pandemic on education, the question arises whether (and how) the pandemic influenced this incorporation.

The study's research questions are as follows:

1. To what extent do online science educational videos include NOS aspects?
 - 1.1 What is the general inclusion of NOS and NOS aspects?

2. How is NOS represented in the videos?
3. If and how did the COVID-19 pandemic influence the presence of NOS aspects in online science educational videos?
 - 3.1 What were the differences in NOS inclusion before, during, and after the COVID-19 pandemic?
 - 3.2 Did the COVID-19 pandemic influence NOS inclusion in videos related to COVID-19 more or less than other videos?

4 Methodology

To answer our research questions, we set out to select five videos for three periods and three topics (45 videos in total). These videos were transcribed and coded. Below, the selection of the videos, the coding, and the subsequent analysis are described.

4.1 Video Selection

Three topics were selected. Given our interest in the impact of the COVID-19 pandemic, vaccines were the first topic. Staying within the biomedical sciences, a second topic was selected that was also common in late secondary education and early undergraduate education, mitosis. Finally, as a control that is not part of biomedical science, a third topic was selected related to astronomy, nucleosynthesis. As such, these topics encompass a wide array of scientific content, ranging from crucial public health concerns to fundamental biological processes and physical phenomena. Our selection is, of course, limited and only serves an illustrative purpose.

In addition, we wanted to investigate whether the COVID-19 pandemic influenced COVID-19-related topics more or less than others. Our assumption is that the more relevant the topic was to COVID-19, the more the video creators would try to deliver contextual information to, for example, counteract misinformation as discussed in the literature review. Therefore, we hypothesize that the degree of relevance between the topic of the educational videos and COVID-19 would directly correlate with the inclusion of aspects related to NOS during, and potentially also after, the COVID-19 pandemic. Our selected topics have a decreasing relation to COVID-19.

4.2 Data Collection

YouTube served as the data source for this study. It was selected due to its status as a highly popular video-sharing network used by over two billion people across the globe (YouTube for Presse [n.d.](#)), accounting for one-third of all internet users (Pelchen, [2024](#)). Additionally, users on this platform watch numerous hours of videos each day, resulting in billions of views (Allgaier, [2018](#); Tume, [2023](#); Van Den Eynde et al., [2019](#)).

The data were collected using the following steps:

- 1) Use the Google Chrome web browser in Incognito mode. Incognito browsing ensured neutral search results, unbiased by personalized browsing history or preferences (Mohamed & Shoufan, [2022](#)).

- 2) Search, on YouTube, the terms “what is mitosis,” “what is a vaccine,” and “what is nucleosynthesis.”
- 3) Apply the Filters on the YouTube platform: Sort by—Relevance, Type—Video, Duration—4–20 min.
- 4) The videos were sorted chronologically based on their views and release dates, categorizing them into three distinct periods: before, during (December 31, 2019–May 5, 2023, WHO 2023), and after the COVID-19 pandemic (May 6, 2023–December 26, 2023, the date of data collection) (for details, see Kim, 2024).
- 5) Eliminated any videos that were irrelevant to the topic, not intended for educational purposes, not in English, and with less than 5000 views.
- 6) Later, due to a scarcity of videos with sufficient views post-COVID, additional videos were selected. The aforementioned procedure (steps 1–4) was repeated.

For each topic, the five videos with the most views were chosen per time period. However, despite conducting a second data collection on February 27, 2024 for the post-COVID pandemic period, the videos on mitosis and nucleosynthesis did not receive enough views post-COVID, which limited us to selecting only one video for analysis on both topics. Table 1 provides an overview of the descriptive statistics of the collected videos.

Table 1 Overview of collected videos

Topic	Period	Max. views	Min. views	Average subscriber	Average length (seconds) (SD)	Average number of sentences (SD)
Vaccines	Before	16,672,325	251,921	11,280,000	441 (168.016)	65.6 (39.272)
	During	12,716,945	2,903,115	8,244,000	422.8 (61.621)	59.2 (5.630)
	After	342,628	7839	3,377,120	391.8 (173.508)	61.6 (29.031)
Mitosis	Before	9,744,829	1,602,914	2,700,600	430.2 (144.695)	73.8 (29.295)
	During	1,452,613	293,339	1,252,600	332.8 (56.503)	52 (11.291)
	After*			15,400,000	670	121
Nucleosynthesis	Before	6,795,648	462,477	6,130,060	663.2 (314.944)	77.2 (29.836)
	During	662,639	6435	202,745	519.8 (280.240)	64.4 (42.711)
	After*			277,000	449	104

*Mitosis and nucleosynthesis topics had one video for the post-COVID-19 period. Thus, only one figure is in the table

4.3 Data Analysis

The selected YouTube videos were transcribed using the Transcript feature on YouTube. When the transcript option was unavailable, we used an online platform to acquire reliable transcriptions. These transcripts were checked manually and corrected where necessary.

Sentences of the video transcripts were coded using the following coding scheme (long sentences were cut into parts that contained a single idea before coding; these parts will also be referred to as “sentences”). For every sentence, we coded which of the seven NOS aspects was present.

Lederman et al. (2007) categorize NOS understanding into either (more) naïve or (more) informed. However, while the questionnaires were used to study participants’ understanding of NOS in an exhaustive manner, the selected videos did not intend to convey NOS in an exhaustive way. Rather, they were designed to convey a scientific topic to a broad audience and may include aspects of NOS. Although educational videos may not comprehensively convey the nuanced and informed elements of NOS, they generally intend to depict science in an accurate and non-misleading manner. Consequently, we embraced the coding criteria published by Abd-El-Khalick et al. (2023), which give more nuanced categorizations: silent, naïve, partially informed, or informed (see Appendix 2, Table 8). While the criteria for categorization are specific to questionnaires, we believe that they can be applied to videos by adjusting them to fit our context. If there was no evidence of any core components (the detailed coding scheme can be found in Appendix 1 (Table 7) and Appendix 2 (Table 8)) of any NOS aspect, the sentence was designated as “silent.” If all core components of a NOS aspect were present in an informed manner, a sentence was coded as “informed.” If there were some components of a NOS aspect present in an informed manner, even with broad interpretation, or if the criteria were only partially satisfied, it was labeled as “partially informed.” Sentences were coded as “naïve” if some or all components of a NOS aspect were present in a strictly naïve manner.

In order to achieve a thorough comprehension of the context, sentences leading up to—and following—each of the sentences were taken into account while coding the sentences. Inter-rater reliability was assessed using Cohen’s kappa coefficient between two researchers, which yielded a value of 0.90, signifying a high level of agreement.

Subsequently, a quantitative analysis was conducted to investigate the influence of the COVID-19 pandemic over time. We employed the Mann–Whitney *U* test to compare the different time periods. Finally, the sentences marked as informed, partially informed, or naïve were analyzed qualitatively using thematic coding. As such, this study utilized a mixed-methods approach to investigate the use of NOS elements in a selection of educational videos.

5 Results

5.1 Inclusion of NOS Aspects (RQ 1.1)

No “informed” NOS statements were found. Partially informed statements about NOS aspects were found up to a maximum of 16 times in a single video (see Fig. 1). Noteworthy is that there was only one out of the eleven mitosis videos that included any NOS

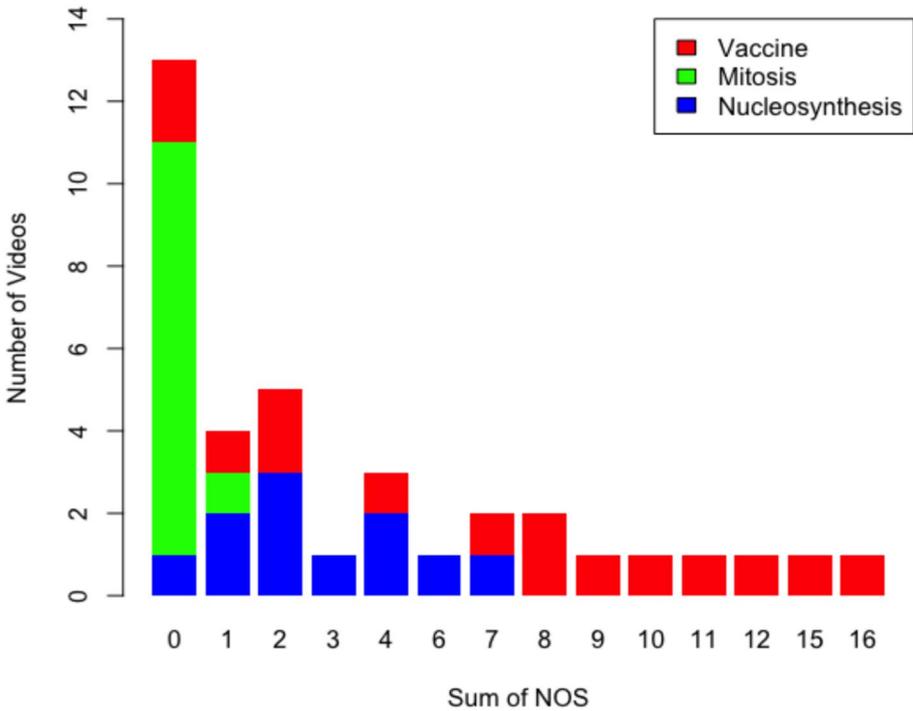


Fig. 1 Frequency of NOS in videos

aspects. Nucleosynthesis videos had between one and seven statements that included NOS per video. Vaccine videos had up to 16 NOS mentions per video.

Not all NOS aspects are mentioned equally frequently (see Table 2). Only a single occurrence of the tentative NOS was identified in the case of mitosis. On the other hand, nucleosynthesis showed a wider range of NOS aspects, with tentativeness being mentioned most frequently (19 times), followed by the empirical NOS (12 times). While other aspects were also mentioned, their frequency was relatively low, with each being referenced less than 10 times.

The analysis of the vaccine topic showed a more comprehensive incorporation of aspects related to NOS. The empirical NOS was mentioned the most, appearing 37

Table 2 Count of sentences mentioning NOS aspects per topic

Topic	NOS 1 Empirical	NOS 2 Method	NOS 3 Tentative	NOS 4 Theories and laws	NOS 5 Creative	NOS 6 Theory laden	NOS 7 Social and cultural
Mitosis	0	0	1	0	0	0	0
Nucleo-synthesis	12	2	19	3	1	3	7
Vaccine	37	5	20	1	20	3	27

Sentences can be marked with multiple NOS aspects

times, followed closely by the social and cultural NOS with 27 instances. In addition, mentions of the tentative NOS and the creative NOS were noteworthy, although they occurred less.

The aspects that were mentioned the least across all three topics include the method NOS, the theories and laws NOS, and the theory-laden NOS.

5.2 Influence of COVID-19 and Comparing Different Time Periods (RQ 3.1 and RQ 3.2)

Table 3 reports the average percentage of occurrences of NOS (in terms of sentences) relative to the total number of sentences in the videos, since longer videos could contain more NOS sentences.

We performed a Mann–Whitney *U* test to determine if there were any significant differences in total sentences mentioning NOS between each pair of two time periods. The results (see Table 4) indicate that there are no statistically significant differences between different time periods for any of the time period– and topic combinations.

As indicated earlier, not all NOS aspects are present equally. As such, the analysis is further detailed at the NOS aspect level. Table 5 indicates the NOS aspect inclusion percentages for vaccine videos across the three observed time periods. Before and during COVID-19, empirical NOS was mentioned the most, at 28.9 and 25% respectively, and it increased to 41.9% after COVID-19. Conversely, the prevalence of social and cultural NOS was 39.5% prior to the onset of COVID-19, but gradually declined to 11.6%. Interestingly, method NOS was mentioned 15.6% during COVID-19, while

Table 3 NOS inclusion—average percentage of NOS sentences within a video per topic and period

Topic	Before	During	After
Mitosis	0.00%	0.00%	0.38%*
Nucleosynthesis	4.51%	5.78%	2.88%*
Vaccine	12.02%	9.23%	11.51%

* Only one video

Table 4 *P*-value of the Mann–Whitney *U* test comparing total amount of NOS sentences at different periods

Topic	Before–during	During–after	Before–after
Nucleosynthesis	0.0508	0.0717	0.4490
Vaccine	0.5189	0.1637	0.4343

Mitosis videos are not included, as there was only one that had a sentence marked as NOS

Table 5 Vaccine—NOS aspects inclusion percentage (NOS aspect sentences/total NOS sentences)

Period	NOS 1 Empirical	NOS 2 Method	NOS 3 Tentative	NOS 4 Theories and laws	NOS 5 Creative	NOS 6 Theory laden	NOS 7 Social and cultural
Before	28.9%	0%	15.8%	0%	13.2%	2.6%	39.5%
During	25%	15.6%	21.9%	0%	15.6%	0%	21.9%
After	41.9%	0%	16.3%	2.3%	23.3%	4.7%	11.6%

it did not appear before or after COVID-19. On the other hand, nucleosynthesis videos (see Table 6) mentioned the tentative NOS the most before COVID-19, at 53.3%. It decreased to 35.7% during COVID-19 but still represented the majority proportion. Empirical NOS increased more than twofold from before to during COVID-19, rising from 13.3 to 28.6%.

5.3 How is NOS Described in the Videos? (RQ. 2)

As shown, not all NOS aspects are present to the same extent. Additionally, the way they are presented differs between topics. We will discuss how the most common NOS aspects are presented in nucleosynthesis and vaccine videos, providing quotes that exemplify our observations. The quotes are labeled by topic (nucleosynthesis or vaccine), time (before, during, or after COVID-19), and a number, as well as a timestamp. e.g., NB2 indicates a nucleosynthesis video that was produced before the COVID-19 pandemic. The mitosis videos are almost exclusively explaining the various stages of the mitotic cycle, providing concise explanations for each phase without any context (empirical, historical, or other). Given that almost no NOS aspects are present in the Mitosis videos, they are not considered in the following.

To introduce the empirical NOS, both nucleosynthesis and vaccine videos reference historical observations of natural phenomena and the inferences derived from them, as well as contemporary research.

‘Even throughout history, the writings of ancient civilizations from all over the world told of suddenly appearing guest stars appearing in the sky, some of which were even visible during the day’ (NB 5, 04:12–04:23).

“In southern France, the international thermonuclear experimental reactor has been looking for ways to refine the fusion process [...] it hopes to be producing plasma using Tokamak technology by 2025” (ND 2, 06:33–06:46).

‘In another paper in 2023, the research group published results demonstrating the strategy worked for treating mice who had a mouse version of multiple sclerosis’ (VA 1, 05:16–05:24).

“In 1796, the scientist Edward Jenner injected material from a cowpox virus into an eight-year-old boy with a hunch that this would provide the protection needed to save people from deadly outbreaks of the related smallpox virus” (VB 3, 00:00–00:22).

Nucleosynthesis videos typically introduce the empirical NOS with a historical context, while vaccine videos often cite contemporary research, clearly specifying the year and the conducted experiment. Nevertheless, we observed that the inferential aspects of the empirical NOS, such as the interpretation of observations and the formulation of

Table 6 Nucleosynthesis—NOS aspects inclusion percentage (NOS aspect sentences/total NOS sentences)

Period	NOS 1 Empirical	NOS 2 Method	NOS 3 Tentative	NOS 4 Theories and laws	NOS 5 Creative	NOS 6 Theory laden	NOS 7 Social and cultural
Before	13.3%	6.7%	53.3%	0%	0%	6.7%	20%
During	28.6%	3.6%	35.7%	7.1%	3.6%	7.1%	14.3%

research or experiments by scientists, were frequently excluded. Thus, these examples are marked as partially informed.

The tentative NOS was frequently discussed in both topics and shared a common characteristic. Both topics employed a substantial number of terms that conveyed uncertainty or the potential for changes, such as “further,” “incomplete,” “until recently,” and “before.” In the following example from the video NB 1, “at that time we did not know” indicates uncertainty in science and “with further development” indicates a change over time.

“At the time we didn’t know about the subatomic particles the radiation was comprised of, so we just name them with Greek letters and discovered their identities later” (NB 3, 02:52–03:02).

“With further development, these vaccines could make a real difference for people struggling with a substance use disorders; and ultimately make quitting easier” (VA 2, 05:29–05:36).

The mentioned references to the Tentative NOS aspect pertain solely to single components, specifically the idea, i.e., “new evidence, made possible through conceptual and/or technological advances, is brought to bear.” Nonetheless, these examples do not thoroughly illustrate that scientific knowledge is dependable and enduring, yet never absolute or certain, nor do they indicate that change may also stem from novel theoretical insights.

Both topics also refer to (global) societal issues that drive the research. These social and cultural NOS aspects emerged predominantly, for both topics, through entire sentences rather than individual words. The following sentence from a nucleosynthesis video implies that climate change provides a reason to research nuclear fusion (the process at the base of nucleosynthesis).

“No greenhouse gases or significant amounts of radioactive waste are produced, making fusion an appealing choice in green power” (ND2, 07:37–07:46).

A similar example from a Vaccine video during the COVID-19 pandemic discussed the prioritization of funding due to the COVID-19 pandemic.

“That speed [of the COVID-19 vaccine development] was driven by billions of dollars, and a global effort” (VD 5, 00:50–00:53)

The examples demonstrate that science can be influenced by social factors, but here too the videos only address the core elements partially.

The creative NOS was frequently discussed in vaccine videos. Most examples highlight that scientists invent theories by using their imagination.

“(She was complaining of a sore throat. So Hilleman looked her over, and determined she had the mumps.) Unable to sleep, he was struck with an idea.” (VD 5, 00:13–00:16).

In 1796, the scientist Edward Jenner injected material from a cowpox virus into an eight-year-old boy with a hunch that this would provide the protection needed to save people from deadly outbreaks of the related smallpox virus. (VB 3,00:00–00:22).

Although these examples indicate, through the words “hunch” and “struck with an idea,” the creative NOS, they do not explicitly convey that scientists use imagination in developing theories, experimental setups, or interpreting data. Rather, the creativity

is implied and left for the viewer to infer from context. Therefore, these examples are marked as partially informed.

The method NOS was one of the least mentioned aspects for both topics.

But each vaccine's trial might be done in very different circumstances. (VD 2,02:48-02:53)

This example indicates that scientific procedures may differ depending on context. Vaccine trials may differ according to circumstances, and cosmological models are applied as considered most appropriate. While this partially aligns with method NOS by implying that science is not a recipe-like process and viewers can infer from it, the videos do not explicitly teach or clarify these elements.

6 Discussion

In the present work, we set out to examine the presence of NOS in science educational videos as well as the influence of COVID-19 on it.

Firstly, our findings indicated that NOS is included in the selected videos. However, the NOS aspects were mentioned in a partially informed manner, if they were mentioned at all, in the selected science educational videos. They often illustrate a NOS aspect through only a single element, lacking the complexity of the NOS that they are describing. Moreover, certain NOS aspects appear to be more prevalent than others across the topics. For instance, the tentative NOS was mentioned the most for the nucleosynthesis topic. This can be due to the characteristics of the topic, a phenomenon that cannot be directly observed; therefore, new, advanced technology and discoveries were needed to change our understanding. The empirical NOS was mentioned the most for the vaccine topic, and it can be interpreted that these videos include more elements related to empirical observation, such as experiments and laboratory measurements.

This outcome could result from the necessity for explanation videos to convey information effectively within a limited timeframe. As such, it might be expected that creators would opt for a more condensed explanation of the content and/or context and exclude elongated explanations about NOS aspects.

The method NOS, theories and laws NOS, and theory-laden NOS were the least mentioned NOS aspects across all videos and topics. This is intriguing because these aspects of NOS are also the ones that students and/or teachers struggle to comprehend (Kartal et al., 2018; Mesci & Cobern, 2020; Sormunen & Köksal, 2014). Perhaps the creators of the videos, like many teachers, also do not fully grasp these NOS aspects (possibly because they are more abstract) and thus failed to convey those aspects. Additionally, these aspects could be perceived as being less conventionally entertaining to the general public. Given the algorithm-based incentives (Hödl & Myrach, 2023) that are thought to reward engagement (in the form of watch time, likes, comments, or even donations) and loyalty (subscribing, returning to the same creator, or watching similar content or creators) (Subha & Bharathi, 2025), it is conceivable that creators favor more accessible NOS aspects, such as the empirical, creative or tentative NOS.

In line with this result, our examination of the collected videos reveals that they do not explicitly address NOS aspects. This absence of explicit NOS inclusion is noteworthy considering that its importance and effectiveness are highlighted in education, as scholars

(Abd-El-Khalick & Lederman, 2000a; Schwartz et al., 2004) mentioned that explicitly teaching NOS is more effective than using implicit methods to alter the learners' perspectives on NOS.

When NOS aspects are only implicitly included, learners may not recognize them or may misinterpret them based on preexisting views. This subtlety may limit the potential of videos to foster a more informed understanding of how science works. Moreover, due to the popularity of YouTube with students, the level of clarity of NOS in videos may have an impact on the public's understanding of science.

In contrast to the classroom setting, viewers may lack access to educators who can clarify or contextualize scientific representations, therefore making the depth and clarity of NOS aspects within the videos crucial. This highlights that science communicators should be encouraged to reference NOS aspects explicitly, in line with the evidence demonstrating the benefits of explicit instruction, as well as the need for collaboration between educators and science communicators to develop content.

Second, our findings also showed that the presence of NOS was not affected by the COVID-19 pandemic, regardless of the closeness of the subject matter to viruses. This result is notable, as we initially expected that COVID-19, which was a globally impactful scientific event, would impact the overall NOS inclusion, especially in the vaccine topic. After all, "science and science-related topics have become an increasingly covered topic in the media due to important discussions regarding scientific phenomena such as the coronavirus (COVID-19) pandemic" (Stamer et al., 2021, p. 868). This enhanced visibility could have provided an opportunity to elucidate the NOS aspects of science to the public.

While COVID-19 did not lead to a general increase in NOS inclusion, upon closer examination, it did have an influence on the presence of specific NOS aspects. Regarding the vaccine topic, the empirical NOS aspect was mentioned 27% before COVID-19 but increased to 41% in the videos made after COVID-19. Keeping the limitations of this study in mind (see further), this could be interpreted as a response to the large amount of misinformation related to vaccines that was spread during the COVID-19 pandemic (Sesa et al., 2022). Perhaps vaccine-related content creators aimed to provide accurate information supported by evidence, such as mentioning specific studies and experiments. Using our coding, this was highlighted as an increase in empirical NOS. At the same time, this emphasis was accompanied by a reduction in the incorporation of social and cultural aspects of NOS, as including these elements could potentially introduce more complexity and uncertainty to the general public. Alternatively, it can also indicate that including one aspect of NOS reduces the opportunity to mention other NOS aspects due to the limited length of the videos.

Intriguingly, we found that the videos on the topic of mitosis did not exhibit any NOS elements prior to and during the COVID-19 pandemic. The primary focus of the content of mitosis videos was to provide an explanation of the cycle. Moreover, we assume that mitosis is often taught as a fundamental biological process involving the replication and division of cells, and it is often perceived as a more straightforward, less controversial process. While this might explain why there is less NOS in mitosis videos, the same could be said about nucleosynthesis. It too is a fundamental process and relatively straightforward, yet these videos do include NOS aspects. This difference indicates that topic characteristics

alone do not entirely explain NOS inclusion, but instead suggests that potential variations in creators' content framing, motives, or production decisions play a role as well.

Some limitations of this study should be noted. Firstly, it is crucial to note that due to the limited number of topics and videos, we cannot make claims about science videos in general. Furthermore, we acknowledge that only a limited number of videos on nucleosynthesis and vaccines were included for the post-COVID-19 period due to their low viewership. It is conceivable that there may be a greater abundance of videos available within other scientific disciplines. To address this, future research could include videos that are over 20 min long and cover a broader selection of various science discipline topics. This should provide a clearer overview of the inclusion of NOS in science educational videos and would provide an opportunity to conduct a more comprehensive thematic analysis. Secondly, certain aspects of the coding process were generously allocated, taking into account the context and sentiment. This approach was necessary because the coding criteria we employed were originally designed for analyzing responses from questionnaires and interviews, which differ fundamentally from video content. We recommend that future research further explores the adaptation of existing NOS frameworks (e.g., the FRA-NOS framework) for the analysis of educational science video content. It might be necessary to create coding criteria specifically designed for educational videos. Furthermore, coding is an inherently subjective process. As Packer (2018) noted, individuals with different interests and varying levels of background knowledge may interpret things in distinct manners. While we checked the inter-rater reliability, in future research, it could be worthwhile to conduct the coding of the videos by several examiners with diverse backgrounds and analyze their comprehension of the videos, as well as the underlying reasons for their interpretations.

7 Implications and Recommendations

The findings of this study revealed that the science educational videos that were chosen seldom incorporated aspects related to NOS. Instead, they primarily concentrated on delivering content without providing detailed information about the epistemic, historical, or developmental aspects of science. These findings have implications for science educators, science communicators, and researchers in both fields.

Science educators should be aware that many educational videos may lack comprehensive NOS coverage and that NOS aspects may not be explicitly mentioned. Therefore, they should critically assess if and when they want to use such videos. Additionally, they will need to supplement these videos to ensure a well-rounded science education, e.g., with discussions and activities that highlight the NOS aspects explicitly. To support teachers in this effort, teacher training could train in- and pre-service teachers to critically evaluate and effectively use science educational videos to develop students' understanding of the NOS.

Science communicators, especially those creating educational videos on platforms such as YouTube, should make a conscious effort to incorporate more elements of NOS into their content. They can incorporate NOS in a more informed way by, for example, highlighting debates among scientists, explaining uncertainty, or situating discoveries within

historical trajectories. This can support the shaping of a more nuanced understanding of science by their audience and, as such, might contribute to strengthening the scientific literacy of the general population.

Furthermore, our research findings indicate that COVID-19 did not have any impact on the inclusion of NOS, contrary to our initial expectations. After all, at a time when science has a larger-than-usual impact on society, it is even more important to educate the public about the nature of the scientific process and scientific knowledge. Moreover, during times of increased public interest and elevated engagement in science, there is an opportunity to improve the scientific literacy of the general population. However, this study shows that this chance was perhaps not fully taken, overlooking the potential for more explicit integration of the NOS in online science educational videos. We suggest that science communicators explicitly incorporate NOS elements, particularly during times or in subjects where public engagement with science is inherently elevated.

Finally, our research demonstrates that there is a need for more research using the NOS framework to analyze science educational videos. Several follow-up questions can be asked. How nuanced are videos that focus specifically on NOS? How nuanced is the NOS presented in videos that focus on historical aspects or events in science, that report empirical research, or explore the human side of science? To what extent do students pick up these NOS aspects when watching these videos (in a class context or at home)? Are some video formats more effective in developing viewers' NOS aspects? What are the affordances of the video format for integrating NOS? Understanding how NOS can be embedded in these resources is essential for enhancing learning outcomes.

8 Conclusion

To summarize, this study examined selected science educational videos on YouTube and revealed that NOS aspects were only mentioned in a partially informed way, if at all. Additionally, we found that COVID-19 had no influence on the general inclusion of NOS, but it did affect the inclusion of specific NOS aspects to a greater or lesser extent.

In order to promote scientific literacy, both science educators and communicators should be cognizant of these observations and should allocate more resources towards creating scientifically informative videos that include explicit statements about NOS.

Appendix 1

Appendix 2

Author Contribution Conceptualization: Jan Sermeus; methodology: Hyoeun Kim and Jan Sermeus; formal analysis and investigation: Hyoeun Kim; writing—original draft preparation: Hyoeun Kim; writing—review and editing: Hyoeun Kim and Jan Sermeus; supervision: Jan Sermeus.

Data Availability Data for this study are available from the corresponding author upon a reasonable request.

Table 7 NOS core elements

Name	Core elements	Example
NOS 1 (empirical)	<p>Empirical</p> <ul style="list-style-type: none"> • Scientific claims are derived from, and/or consistent with, observations of natural phenomena, and/or • Reliance on empirical evidence (i.e., observations of natural phenomena) is a characteristic that distinguishes science from other disciplines of inquiry, and/or • Scientific claims are supported and/or eventually adjudicated by reference to empirical observations <p>Inferential</p> <ul style="list-style-type: none"> • Scientists do not have “direct” observational access to most natural phenomena, and/or • Scientific constructs (atoms, force fields, gravity, etc.) are inferential: They can only be accessed and/or measured through their manifestations or effects, and/or • Observations and inferences are distinct • Observations are descriptive statements about natural phenomena that are accessible to the senses (or extensions of the senses), and about which observers can reach consensus with relative ease • Inferences are statements about phenomena that are consistent with empirical observations but not directly accessible to the senses 	<p>Naïve</p> <p>Science is something that is straightforward and fact-based. It was observed that Mitosis is the separation of nuclear chromosomes into two identical daughter</p> <p>Partially informed</p> <p>Science is one of the means for understanding the world we live in. There is no set way to do science, but it is the process by which we understand the world by collecting observations</p> <p>Informed</p> <p>Much of the development of scientific knowledge depends on observation. ... [But] I think what we observe is a function of convention. I do not believe that the goal of science is (or should be) the accumulation of observable facts. Rather, science involves abstraction, one step of abstraction after another</p>

Table 7 (continued)

Name	Core elements	Example
NOS 2 (method)	<ul style="list-style-type: none"> • There is not a recipe-like stepwise procedure that typifies all scientific practice, or • No single “Scientific Method” guarantees the development of infallible knowledge, or • There is no single sequence of (practical, conceptual, and/or logical) activities that will unerringly lead scientists to valid scientific claims 	<p>Naïve</p> <p>Science deals with using an exact method. That way, we know we have the right answer. There is an agreed method that all scientists use in acquiring that evidence, and this is the only way to do it</p> <p>Partially informed</p> <p>An experiment is the means by which we test our hypothesis. There is no set way to do an experiment. Sometimes a hypothesis will be proven through trial and error, by lucky chance, or by a systematic way in which it is done</p> <p>Informed</p> <p>There is no one way to do an experiment. Sometimes a hypothesis will be proven through trial and error, observation, or measuring</p> <p>This is the best way or most common way to do it</p> <p>Compared to philosophy and religion, science demands definitive, right, and wrong answers</p> <p>Theories must change to reflect new observations made with better instruments. New tools that allow us to view things that had never been observed necessitate theories to be changed to accommodate new data, or abandoned altogether</p> <p>Everything in science is subject to change with new evidence and the interpretation of that evidence. We are never 100% sure about anything because ... negative evidence will call a theory or law into question, and possibly cause a modification</p>
NOS 3 (tentative)	<ul style="list-style-type: none"> • Scientific knowledge is reliable and durable, but never absolute or certain, and/or • All categories of scientific knowledge (“facts,” theories, laws, etc.) are subject to change, and • Scientific knowledge is subject to change as • New evidence, made possible through conceptual and/or technological advances, is brought to bear, and • Extant evidence is reinterpreted in light of new or revised theoretical ideas, or shifts in the directions of established research programs or traditions 	<p>Naïve</p> <p>Partially informed</p> <p>Informed</p>

Table 7 (continued)

Name	Core elements	Example
NOS 4 (theory and laws)	<p>Scientific theories</p> <ul style="list-style-type: none"> • Scientific theories are • Highly corroborated: Well-established, highly substantiated, and • Explanatory: Unify or account for large sets of seemingly unrelated observations in several fields of investigation, and • Generative: Generate research questions and problems, and/or guide future investigations, and • Predictive: Allow scientists to make specific predictions, sometimes beyond their original scope, and • Theories are tested indirectly • Direct testing is untenable, or • Only indirect evidence supports or validates theories, or • Scientists derive specific testable predictions from theories and check their agreement with observations <p>Agreement increases confidence in the tested theory</p> <p>Scientific laws</p> <ul style="list-style-type: none"> • Scientific laws are • Statements or mathematical formulations that describe relationships among observable phenomena or attributes of these phenomena (e.g., between the pressure and temperature of a confined amount of gas), and • Never absolute, or subject to change, or • Not universal in the sense that they only apply within the limits of specified conditions (e.g., gas laws only apply in the case of ideal gases) 	<p>Naïve</p> <p>Partially informed</p> <p>Informed</p> <p>When multiple theories are supported, it becomes a law</p> <p>A law attempts to predict, while a theory attempts to explain. The existence of a law assumes the uniformity of nature... Hence, a law not only tells what happens (in mathematical forms, or word statements), but also predicts what will happen. A theory attempts to explain why certain things happen</p> <p>Theories and laws are different forms of knowledge. Theories... serve to explain why or how something occurs, while laws generally are statements about what happens or is observable</p>

Table 7 (continued)

Name	Core elements	Example
NOS 5 (creative)	<ul style="list-style-type: none"> • Generating scientific knowledge involves human creativity in the sense of scientists inventing theories, theoretical entities, and/or explanations, and/or • Creativity is involved in all stages of scientific investigation, including prior to, during, and following the collection of data, and is particularly relevant to interpreting data and generating conclusions from these data, and/or • While necessarily rational and systematic in several respects, scientific investigation cannot be reduced to a merely rational and systematic activity: Human creativity plays a crucial role 	<p>Naïve</p> <p>There is no creativity after data collection because the scientist has to be objective</p> <p>Partially informed</p> <p>I think scientists use their creativity throughout all stages of their investigation... There is a lot of evidence that can be used to prove their hypothesis... To select the most appropriate data... and to analyze their data economically, creativity is one of the most essential qualities of scientists</p> <p>Informed</p> <p>Scientists use their imagination and creativity at any time during the process. They use imagination and creativity because they cannot directly observe what is occurring... They use them to see things that will fit with their own hypothesis</p>
NOS-6 (theory-laden)	<ul style="list-style-type: none"> • Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, and/or expectations influence their work. These background factors affect scientists' • Choice of problems to investigate and methods of investigation, and/or • Observations, both in terms of what is and is not observed, and/or • Interpretation of observations, or • Science rarely, if ever, starts with neutral observations: Observations are always motivated and guided by, and acquire meaning in light of, questions and problems derived from certain theoretical perspectives 	<p>Naïve</p> <p>Scientists are very objective because they have a set of procedures they use to solve their problems. Artists are more subjective, putting themselves into their work</p> <p>Partially informed</p> <p>Next logical steps after an mRNA vaccine are DNA vaccines</p> <p>Different conclusions are possible because data can be interpreted in multiple ways. Several factors are involved when looking at data, and no data set is a perfect measure of what happened... the truth of the matter will never be fully known</p> <p>Informed</p> <p>Scientists are human. They learn and think differently, just like all people do</p> <p>They interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge</p> <p>The scientist researched mRNA vaccines for years, and due to that, they found a way to develop a DNA vaccine</p>

Table 7 (continued)

Name	Core elements	Example
NOS-7 (social and cultural)	<ul style="list-style-type: none"> ● Science affects and is affected by various social and cultural elements and spheres (e.g., philosophy, religion, worldview, and political and economic factors), or ● Interactions between science and the social and cultural milieu in which scientific practice is embedded are manifested through ● Public funding for scientific research based on social priorities (e.g., funding AIDS versus Ebola research) and/or cultural values (e.g., stem cell research), or ● In some cases, the nature of “acceptable” explanations of natural phenomena (e.g., changing stories of hominid evolution in relation to the advent of feminist perspectives in the biosocial sciences) 	<p>Naïve</p> <p>There exists a best explanation for any particular natural phenomenon, and given appropriate scientific rigor, scientists of any culture will eventually draw the same conclusion</p> <p>Partially informed</p> <p>I do believe that science reflects social and cultural values... Religion affects types of science where there is a debate about how people view scientific theories and problems... [Consider] the idea of creationism and intelligent design... there are scientists trying to determine whether or not to support this based on their personal background. Evidence may be universal, but the human interpretation is where science has the chance to be skewed [emphasis added]</p>
		<p>Informed</p> <p>Science reflects social and cultural values of a society because those values determine the types of questions, problems, or phenomena that are invested in and investigated. All factors in society and culture influence the acceptance of scientific ideas. ... Like the theory of evolution that was not accepted in France and was totally endorsed in Germany for basically national, social, and also cultural elements</p>

Adapted from Abd-EI-Khalick et al. (2023) and Lederman et al. (2002)

Declarations

Table 8 Coding criteria

Category	Criteria adapted from Abd-El-Khalick et al. (2023)	Modified criteria in this study
Silent	<ul style="list-style-type: none"> • No relevant response, or • Irrelevant or incomprehensible response, or • Response cannot be reliably categorized 	<ul style="list-style-type: none"> • No relevant sentence, or irrelevant sentence
Naïve	<ul style="list-style-type: none"> • Either some or all core elements of the target NOS aspect are naively addressed, and • Respondent is silent on core elements that are not addressed, and • Respondent is either silent on related NOS aspects or ascribes to equally naïve views of these aspects 	<ul style="list-style-type: none"> • Either some or all core elements of the target NOS aspect are naively addressed, and/or • The sentence is either silent on other NOS aspects or ascribes to equally naïve views of these aspects
Partially informed	<ul style="list-style-type: none"> • Only a subset of the core elements of the target NOS aspect is judged to be informed, and • Respondent is silent on other core elements of the target NOS aspect, and • Related NOS aspects are not naively addressed 	<ul style="list-style-type: none"> • Only a subset of the core elements of the target NOS aspect is judged to be informed, and • Other NOS aspects are not naively addressed
Informed	<ul style="list-style-type: none"> • All core elements of the target NOS aspect are judged to be informed, and • Respondent is silent on related NOS aspects, or • Related NOS aspects are not naively addressed 	<ul style="list-style-type: none"> • All core elements of the target NOS aspect are judged to be informed, and • Other NOS aspects are not naively addressed

Conflict of interest The authors declare that they have no conflict of interest.

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