Part 6 / Strand 6

Nature of Science: History, Philosophy and Sociology of Science

Editors: *Ebru Kaya & Veli-Matti Vesterinen*

Part 6. Nature of Science: History, Philosophy and Sociology of Science

The implications of nature of science, its history, philosophy, sociology and epistemology, forscience education. The significance of models and modelling for science education as reflected in the particular importance attached to the use of metaphors, analogy, visualization, simulations and animations in science.

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Part 6: Nature of Science: History, Philosophy and Sociology of Science

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Introduction

In the age of social media, science and scientific perspective seem to be constantly challenged. In addition, growing concerns over disinformation have highlighted the need to improve students' understanding of what science is, how it operates, and how it can contribute to solving global challenges we face. Thus, understanding the Nature of Science (NOS) is seen as an integral part of scientific citizenship.

Two studies presented in Strand 6 (Nature of Science: History, philosophy and sociology of science) were accepted to be published in the ESERA 2021 conference proceedings. Both papers address the issues of teaching NOS.

The first paper by Jan Winkelmann focuses on the beliefs and attitudes about the importance of idealisations within the genesis of scientific knowledge in a teaching context. The author presents a questionnaire including three scales: Epistemological Beliefs on Idealisations in Natural Sciences, Epistemological Beliefs on Dealing with Idealisations in Science Education, and Actual Teaching Practice in Dealing with Idealisations. The questionnaire was developed for teachers to ascertain their perspective on the meaning of idealisations as part of Idealisations in Modelling and Experimentation (IDOMEX) research program.

The second paper was written by Constantina Stefanidou and Constantine Skordoulis. They investigated how pre-service primary teachers plan to teach NOS in their future classes in light of the COVID-19 pandemic. The pre-service primary teachers wrote a report on creating a teaching scenario on NOS. The content analysis results show that most pre-service primary teachers focused on the empirical character of science and the fact that scientists are influenced by their previous beliefs, along with the tentativeness of science and the influence of the social and cultural aspects.

EPISTEMOLOGICAL BELIEFS ON IDEALISATIONS IN SCIENCE TEACHING – CONSTRUCTION AND VALIDATION OF A QUESTIONNAIRE

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Epistemological beliefs denote personal subjective views, conceptions, and theories about the genesis, ontology, meaning, justification, and validity of knowledge in the sciences. In this context, views of Nature of Science, in general, are often ascertained in science education research. In particular, this paper's subject is the beliefs and attitudes (focusing on the teaching process) about the importance of idealisations within the genesis of scientific knowledge. Idealisations are omnipresent in scientific knowledge acquiring when dealing with models and experiments. Inadequate addressing of idealisations in the teaching context suggests learning difficulties for students. As part of the research program IMODEX (Idealisations in Modelling and Experimentation), a questionnaire was developed for teachers to ascertain their perspective on the meaning of idealisations. The focus is on three scales: 1. Epistemological Beliefs on Idealisations in Natural Sciences, 2. Epistemological Beliefs on Dealing with Idealisations in Science Education, 3. Actual Teaching Practice in Dealing with Idealisations. The questionnaire was constructed based on a pilot study with 103 students in 2020 and revised for a second pilot study in 2021 with science teachers. By using multiple regression analyses, the aim is to obtain recommendations for action on what should be emphasised in training and further education so that idealisations play a more significant role in teaching. The further development of the questionnaire based on the second pilot study with science teachers is presented in this paper.

Keywords: Idealisations, Nature of Science, Beliefs

THEORETICAL BACKGROUND

One primary goal of science education is to give students a better understanding of science concepts and contexts. This goal means having good content knowledge of different domains, e.g., physics, chemistry, or biology, and having adequate beliefs about how science works, assigned to the field Nature of Science (NOS). Together with experiments, models represent the two pillars of scientific knowledge acquisition, which are always based on idealisations. Suppose teachers do idealisations not make to explicit objects of learning (e.g., in models as epistemic artifacts, Gilbert & Justi, 2016, 17). In that case, one can assume that poor consideration with idealisations prevents students from developing appropriate concepts of scientific knowledge acquisition. Reflecting on the meaning of underlying idealisations in models and experiments can contribute to developing the abilities mentioned above. However, in previous approaches to epistemological beliefs in the natural sciences (e.g., Conley et al., 2004) and current research on modelling competence (e.g., Gilbert & Justi, 2016), the cross-sectional topic of idealisation appears to be underrepresented (Winkelmann, 2021a).

Epistemological Beliefs

Epistemological beliefs denote personal subjective views, conceptions, and theories about the genesis, ontology, meaning, justification, and validity of knowledge. Such beliefs show across contexts some stability but can also differ across domains and topics (Muis et al., 2006; Sandoval et al., 2016). In the discourse of science education research, epistemological beliefs are located in the context of NOS (Hofer & Pintrich, 1997, Lederman & Lederman, 2014). The research focus is on a broad understanding of NOS, e.g., the epistemological significance of models and experiments in the process of scientific knowledge acquisition (Urhane & Hopf, 2004; Priemer, 2006). Conley et al. (2004) conceptualised a widely recognised model of epistemological beliefs in science with four dimensions: certainty, development, source, and justification of knowledge. Building on this, a series of studies on students' epistemological beliefs and relations between epistemological beliefs in science and student learning characteristics were carried out and recently brought together in Schiefer et al. (in press).

Idealisations in Science and Science Education

All processes of scientific knowledge acquisition are based on idealisations. Be it experimenting, in which a (natural) phenomenon is examined in the laboratory under ideal conditions, or in dealing with models, only those aspects of the phenomenon that are of interest are considered. Such a willingly adjustment compared to reality is not unusual to scientists. Science teachers will also report that they idealise in very different areas in their lessons, for example, with (air) friction in mechanics or with thin lenses in optics. Based on previous considerations on the relationship between theory, model, and experiment, the yellow box in Figure 1 illustrates the linking character of idealisations (Winkelmann, 2019).

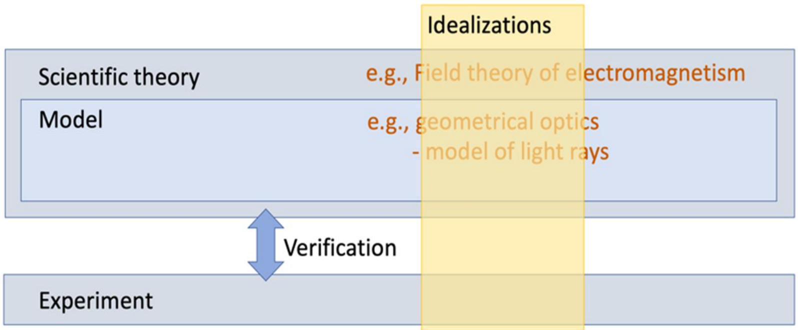

Figure 1. Idealisations take place in all areas of scientific knowledge acquisition.

To promote students' modelling and experimenting competence, it should be conveyed how to construct a model or design an experiment, namely with idealisations. Accordingly, this research program's underlying thesis is that idealisations should be explicitly identified and reflected upon in teaching to achieve an improved understanding among students. To meet this requirement, a definition of idealisation is necessary. In the following, suggestions from the philosophy of science define what is to be understood by idealisations. When science discusses idealisation, it is about approaching a complex reality. For this purpose, individual properties of an object under consideration are consciously replaced. The focus is only on those properties that are felt to be essential for an investigation's goal (Nowak & Nowak, 1998; Strevens, 2017). The aim is to be able to answer a question about nature. Idealisations are based on the requirement of optimising an explanation: In the search for knowledge, idealisations are deliberate substitutions for an original. False assumptions are consciously accepted (Hüttemann, 1997). Idealisations, therefore, have two related properties. On the one hand, idealisations are limited to the essentials. It depends on the question of what is essential in each case. On the other hand, idealisations always represent a deliberately falsifying substitution.

Despite this falsification, it is undisputed that, for example, an evaluation of constructed models is justified concerning their usefulness and not with a view to whether these models are "right" or "wrong".

METHOD

The research program IMODEX (Idealisations in Modelling and Experimenting) examines the importance of idealisations for science education. As a first step, a questionnaire was developed for teachers to ascertain their perspective on the meaning of idealisations. The focus is on three scales: 1. Epistemological Beliefs on Idealisations in Natural Sciences, 2. Epistemological Beliefs on Dealing with Idealisations in Science Education, 3. Actual Teaching Practice in Dealing with Idealisations.

The questionnaire was revised based on initial testing of the scales with 103 students (1st pilot study in 2020). The items of the first scale, "Epistemological Beliefs on Idealisations in Natural Sciences", fit well with the found factor in terms of content but load weak and should be reformulated again. For the scale "Epistemological Beliefs on Dealing with Idealisations in Science Education", an explanatory factor analysis provides indications that a differentiated survey using the two subscales "Concrete Teaching of Idealisations" and "General Importance of Idealisations in Science Lessons" is valid. Additional items for the "Actual Teaching Practice in Dealing with Idealisations" scale had to be constructed to obtain possible subscales (Winkelmann, 2021b).

During an online teacher survey (2nd pilot study, in summer 2021), the questionnaire was piloted by 62 science teachers on a 5-point Likert scale (1 = "does not apply at all" to 5 = "fully applies"). To analyse the scales used, explanatory factor analyses (with maximum likelihood method and varimax rotation) were carried out using SPSS. The modified scales - known from the first pilot study - were again subjected to exploratory factor analyses to identify possible subscales. The conditions for the factor analyses appear to be given for the respective scales (KMO test achieves sufficiently high to very good values: $KMO_{natural\ science}$: .613, $KMO_{science\ education}$: .907, $KMO_{Teaching}$: 773; Bartlett's test is significant in each case: p <.001). However, the sample size is relatively small (according to Bühner, 2006, just enough), so the results should be cautiously interpreted.

RESULTS

The three scales were each subjected to exploratory factor analysis. Summing up, the three scales and their subscales are presented in table 1. In addition, the table gives an example item for each scale and names the number of items as well as the respective reliability (Cronbach's α).

Table 3. Overview of the analysed scales.

Title of the Scale	Sample Item	Number
Epistemological Beliefs on Idealisations in Natural Sciences (• = .72)	see below	8 items
Meaning of Idealisations in Natural Sciences (• = .75)	*Idealisations are omnipresent in scientific knowledge acquisition.*	4 items

Experimenting (• = .68)	*Meaningful experimental findings can only be achieved with idealisations.*	3 items
Model Construction (• = n.a.)	*Idealisations are the basis for the construction of models.*	1 item
Epistemological Beliefs on Dealing with Idealisations in Science Education (• = .86)	*In my opinion, idealisations should be made an explicit subject in science lessons.*	8 items
Actual Teaching Practice in Dealing with Idealisations (• = .93)	see below	18 items
Student Action in Experimenting and Modelling (• = .89)	*My students usually identify idealisations in the models used.*	6 items
Cognitive Consideration of Teacher (• = .88)	*I often think about idealisations in science classes.*	3 items
Explicit-Reflective (• = .82)	*In my lessons, idealisations serve to reflect on an experiment that has been carried out.*	6 items
Model Construction (• = .77)	*In my lessons, we construct models with the help of idealisations.*	3 items

Scale „Epistemological Beliefs on Idealisations in Natural Sciences“

Initially, this scale comprised 14 items. The exploratory factor analysis suggests four factors (eigenvalue criterion and scree plot). Due to partly weak loads on the factors and a subsequent content-related consideration, six items were removed. Another exploratory factor analysis points to three factors. The values of the Measure of Sample Adequacy (MSA) are higher than .5 (except for the item on the "Model Construction" subscale. However, due to the importance of the content, this item was retained, and additional items will be developed, similar to the "Experimenting" subscale). The three factors together explain 54.9% of the variance in the data. The loadings are each sufficiently strong (> .41), and the different factors (subscales) are easy to interpret.

Scale „Epistemological Beliefs on Dealing with Idealisations in Science Education“

Initially, this scale comprised eleven items. The exploratory factor analysis suggests three factors (eigenvalue criterion and scree plot). Due to partly weak loads on the factors and a subsequent content-related consideration, three items were removed. Another exploratory factor analysis points to one factor. The values of the MSA are higher than .8. The factor explains 55.6% of the variance in the data. The loadings are each sufficiently strong (> .41).

Scale „Actual Teaching Practice in Dealing with Idealisations“

Initially, this scale comprised 20 items. The exploratory factor analysis suggests four factors (eigenvalue criterion and scree plot). Due to partly weak loads on the factors and a subsequent content-related consideration, two items were removed. Another exploratory factor analysis points again to four factors. The values of the MSA are higher than .6. The four factors together explain 61.8% of the variance in the data. The three factors together explain 54.2% of the variance in the data. The loadings are each sufficiently strong (> .41), and the different factors (subscales) are easy to interpret.

CONCLUSIONS AND OUTLOOK

Thinking about idealisations in modern sciences is nothing new. However, reflection on idealisation seems underrepresented in science education and science education research. Students should gain an adequate understanding of and beliefs about the nature of science, particularly about the meaning of idealisations. A framework with categories of idealisations is available (Hüttemann, 1997) and discussed and illustrated in Winkelmann (2021a). Furthermore, current considerations with idealisations in the classroom should be surveyed. In addition, it seems useful to investigate teachers' beliefs on idealisation in science and science education.

As part of two pilot studies, a questionnaire was developed for this purpose, including the three scales presented above. After the structure-discovering analyzes have been carried out, validity checks now follow. The content validity is checked within the framework of guided interviews with teachers. The convergent validity is tested regarding a scale from Conley et al. (2004). After that construct validity check, a teacher survey is currently planned to identify the role of idealisations in science teaching. The survey is intended to analyse teachers' epistemological beliefs on the importance of idealisations in science and science education.

It is assumed that only the teaching teacher can initiate a reflection on idealisations. Depending on the actual attention teachers' pay to idealisations, they should be sensitised to this topic during their studies or further training. Using multiple regression analyses, the aim is to obtain recommendations for action on what should be emphasised in training and further education so that idealisations play a more significant role in teaching. In the long term, intervention studies should examine the effect of reflecting on idealisations on students' understanding. Such research would allow students to develop an awareness of their thinking processes when modelling and experimenting. It provides strategies for teachers to develop learning outcomes related to NOS.

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TEACHING NATURE OF SCIENCE IN THE LIGHT OF COVID-19 PANDEMIC CRISIS

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COVID-19 pandemic which began in the end of 2019, changed the whole world. Inevitably it influenced every aspect of education. During the pandemic, we watch how science and scientists struggle between the required scientific research in the level of understanding how the new coronavirus functions, at the level of producing effective drugs and vaccines and at the level of communicating the necessary information to people, to effectively protect themselves. In this paper, we examine how pre-service primary teachers plan to teach Nature of Science in their future classes and especially which Nature of Science aspects they emphasize in the light of the COVID-19 pandemic. The sample, which was a convenient one, consisted of 296 pre-service primary teachers, 272 females and 24 males. Data collection involved the report they wrote at the end of an undergraduate course, called Didactics of Science, which included both lectures and laboratory exercises, in the context of which they were asked to create a teaching scenario on Nature of Science. The qualitative content analysis method was used to analyze the data. The analysis showed that most pre-service primary teachers set as teaching goals the empirical character of science and the fact that scientists are influenced by their previous beliefs, along with the tentativeness of science and influence of the social and cultural milieu. Further research includes content analysis in pre-service teachers' teaching scenarios regarding the activities and the educational material they proposed.

Keywords: Science education, nature of science, socio-scientific issues

INTRODUCTION – THE CONTEXT

The COVID-19 pandemic outbreak has provided an opportunity to get a pulse on how well our society understands science processes. Everyday media provide scientists' findings about the virus as well as predictions, and speculations from doctors and political leaders. These predictions and speculations have changed dramatically over time and sometimes contradict each other (Bloom & Fuentes, 2020).

An example of such contradiction was between findings that supported that that young people are mostly unaffected by the virus, and those findings some weeks later, which revealed a connection between COVID-19 and Kawasaki Disease in children. Further, children are indeed succumbing to COVID-19, and the numbers of children with the disease are likely far undercounted (Lerner, 2020). A World Health Organization (WHO) official drew strong pushback from medical experts when she stated in a press conference that asymptomatic people spreading the disease was "very rare;" she later clarified that the actual number of cases caused by asymptomatic transmission is unknown (Joseph, 2020). But by then, the "the wrong message" had been transmitted. People who doubted the seriousness of COVID-19 used this miscommunication as justification to avoid wearing masks when in public. Others considered this another example of how scientists just do not know what is going on, cultivating a mistrust of science in general.

COVIS-19 pandemic which changed the whole world inevitably, influenced every aspect of education; science education included. It was this time of the year that the authors of this article started the course Didactics of Science in the Department of Primary Education, of National and Kapodistrian University of Athens. The course included both lectures and laboratory classes, where pre-service teachers were engaged to teaching and learning Nature of Science (NoS), through a couple of activities, which varied between historically based and socio-scientific issues (Allchin, 2013; Irwin, 2000; Kolsto, 2001; Klopfer, 1997; Stefanidou et al., 2020).

The arising question was how pre-service teachers' experience of the pandemic has influenced them in designing a teaching scenario for teaching their students NoS through a burning socio-scientific issue such as the COVID-19 pandemic? As McComas et al (1998) have pointed out, NoS is something like how the game of science is played. The "game" of science related to COVID-19 pandemic, a socially significant and culturally important issue, offers some opportunities to realize how science, society, technology, politics interrelate and ask for people's conceptualization, collaboration, and action.

The research is part of a broader study on how pre-service teachers in the era of pandemic conceptualize and design teaching proposals regarding several aspects of NoS. In this paper, the research question is which aspects of NoS do pre-service teachers allege as more important if they were to teach NoS in the context of COVID-19 pandemic and how do they justify them?

METHOD

Fieldwork was carried out at the Department of Primary Education, of the National and Kapodistrian University of Athens, during the spring semester of 2019-2020, from March to June 2020. The Didactics of Science Course included fifteen lectures on topics such as scientific literacy, history, and philosophy of science in science teaching, the role of experiment in science teaching and the inquiry-based teaching and learning model in addition to four associated laboratories during which pre-service teachers had the opportunity to design their own teaching scenarios. All participants were engaged to at least one lecture regarding NoS ideas in addition to an associated laboratory exercise regarding teaching NoS. During the lecture, emphasis was given to "Keys to Teaching the Nature of Science" (McComas, 2004) as a context for elaborating how science and scientists work. In the context of the associated lab, pre-service teachers were engaged to activities regarding the distinction between science and pseudo-science, the role of empirical evidence and the difference between observations and inference, the role of scientists' prior ideas in knowledge development and the interrelation between science and society.

The sample consisted of 296 fourth year university prospective primary teachers, 24 males and 272 females, who undertook the Didactics of Science Course and were selected due to convenient access. All participants designed a teaching scenario on Nature of Science as part of their final assessment (response rate 100%). They were asked to "imagine" the school year 2030-2031 and design a teaching scenario to familiarize twelve years old students with NoS aspects in the context of COVID-19 recent pandemic. As a result, 296 teaching scenarios were collected and analyzed according to their teaching goals.

This study follows a qualitative descriptive cross-sectional research approach. Qualitative content analysis method (Mayring, 2000) and descriptive statistics were used to quantify the findings and present a clearer picture of what pre-service primary teachers find important to teach about NoS understanding (Gay, Mills & Airasian, 2012).

RESULTS

First findings are available in Table 1. Most of the participants recognized as important aspects to teach in twelve years old students the role of empirical evidence in science (72%) and the idea that science has a subjective element (56%). Regarding the empirical character of science, participants' main argument was that during COVID-19 pandemic scientists had to wait until an adequate amount of evidence was gathered before the first findings regarding the modes of transmission were explained and modes of protection and treatment were developed. Regarding the subjective element of science, pre-service primary teachers argued that scientists had different opinion on the same topic, due to their prior beliefs and perspective. They referred to the example of experts' different opinions regarding whether children are super spreaders of COVID-19 or not. Moreover, 48% of pre-service teachers found important to teach that there are cultural and social influences in science. Most of them focused on the negative impact of the pandemic in every aspect of social life, such as the school lockdown and the measures of social restriction. Few of them referred to the controversial role of religious leaders towards the spread of pandemic, giving religious advice to a scientific problem, such as COVID-19 pandemic. Regarding the aspect that scientific knowledge is tentative, about half of the participants (46%) found it important to be taught, underlining that during the pandemic experts' instructions to citizens differed from day to day. Such instructions included diverging ideas, from "masks do not protect" to "masks are compulsory in all publicly accessible areas". Pre-service teachers argued that science is not dogmatic and scientific findings change in the light of new evidence and research. Participants argued that COVID-19 revealed that science is more complex than expected and recognized that it is the first time that science's complexity comes to surface.

Table 1: Pre-service primary teachers' priorities for teaching NoS.

Key aspects on teaching NoS (McComas, 2004)	Pre-service primary teachers (%)
Science demands and relies on empirical evidence	72
Science has a subjective element	56
There are historical, cultural, and social influences on science	48
Scientific knowledge is tentative but durable…	46
Science and technology impact each other, but they are not the same	32
Science and its methods cannot answer all questions	26
Knowledge production in science includes many common features and shared habits of mind … there is no single step-by step scientific method by which all science is done	20
Science is a highly creative endeavor	18
Laws and theories are related but distinct kinds of scientific knowledge	-

Regarding the relationship between science and technology, 32% of the pre-service teachers found important to introduce their students to this aspect. They argue that since COVID-19 outbreak, technological developments from different types of diagnostic tests and protective masks to innovative mRNA vaccine technology interact with science enabling the deepen explanation and prediction of COVID-19 related phenomena. Nearly one quarter of the participants (26%) included in their teaching goal the aspect of NoS according to which science and its methods cannot answer all questions. Although this NoS aspect refers to questions that are not scientific, such as "which kind of music do you like?", pre-service teachers used as examples the unanswered questions related to COVID-19 pandemic such as "why do some people with COVID-19 get sicker than others"? Regarding the role of scientific method in "science in the making", the 20% of pre-service teachers found it important to be included in their teaching goals. They argue that although scientific research against COVID-19 includes some common features, such as constructing hypotheses, providing evidence, experimentation and modelling, every scientist or research team apply its own specific procedures in developing scientific products, such as theories, explanations, or predictions. Pre-service teachers underlined that not all scientific inquiries regarding COVID-19 follow the same steps. Regarding the creativity of science, the 18% of the pre-service teachers found it important to be taught in the context of NoS teaching, supporting that crisis is a strong driver of creativity and innovation in science and beyond. For example, pre-service teachers referred to the innovative idea of mRNA vaccination technology and the 3-D printing face masks in order to meet the desperate need for protective masks during the pandemic. Finally, pre-service teachers did not propose the differences between laws and theories in science as teaching goal for NoS teaching in the context of COVID-19 crisis.

CONCLUSIONS - DISCUSSION

The research revealed that most pre-service primary teachers found COVID-19 pandemic a fruitful context to think and teach aspects of NoS. Their experience during the pandemic helped them recognize as important aspects of NoS the empirical character of science and its subjective element along with the tentativeness of science. Regarding the social and cultural influences on science, most of pre-service primary teachers emphasized on the interruption of social activities and only a few revealed concerns related to the position of the governments, the availability of the vaccine without restrictions by the pharmaceutical companies and the role of church to the spread of COVID-19.

Findings of the present study provoke some additional thoughts. The study took place in the beginning of the pandemic, from March to July 2020. World Health Organization Director-General Tedros Adhanom Ghebreyesus, referring to the pandemic, said, "We're not just fighting an epidemic; we're fighting an infodemic," (Barzilai & Chinn, 2020, p. 107). This infodemic calls attention to the importance of questioning the reliability of the information and its source: explanations from scientists, politicians, and healthcare providers in media; and speeches of several nonexperts on TVs as well as the rapid spread of information and misinformation in social media (Mugaloglou et al., 2022). This complex situation drove to scientists' mistrust, which gives rise to further pseudo-science scenarios. Research reveals that during the pandemic people could not cope with the tentative and subjective aspects of NoS, and this fact made a lot of people lose their trust in science. It is a positive finding of this research, that pre-service teachers designed NoS teaching scenarios based on the pandemic, focusing on the empirical, tentative and subjective NoS which is considered to be key-issues of NoS.

Moreover, almost half of pre-service teachers suggested teaching goals related to the socio-cultural aspects of NoS. This finding has increased importance if we take into consideration the fact that COVID-19 pandemic is a socio-scientific issue, which engages not only scientists and doctors, but also policy leaders, journalists and policy makers. Pre-service teachers that referred to this aspect avoided raising the issue of the relationship between science, politics and religion, maybe in order to keep equilibrium between science and policy making or because they find primary students too young to familiarize them with such issues.

Regarding future considerations, further analysis in pre-service primary teachers' teaching scenarios should shed light on the teaching approach, activities and resources they used in order to *teach* the above-mentioned aspects of NoS. It seems that aspects such as the empirical and tentative aspect of science seem to be more manageable for pre-service teachers related to aspects such as the politicization of science and churches' role during the pandemic, which seem to be more controversial. Maybe it is time for re-considering the role of science education in the light of modern socio-scientific issues in the post covid era (Dillon & Avraamidou, 2020) or in other words it is "time for action" (Hodson, 2003) in order science education to find its position in 21st century society.

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