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Understanding of Nature of Science (NOS) in pre-service teachers with different science content knowledge, before and after an intervention

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ABSTRACT

There is worldwide agreement that the understanding of the Nature of Science (NOS) is a critical component of scientific literacy. However, evidence indicates that both pre-service and in-service science teachers hold naïve views about NOS. Even so, the characteristics of pre-service teachers that influence their learning of NOS are not fully described. In this context, the goal of this study is to connect the understanding of NOS of pre-service teachers with a different disciplinary training (second year of biology education programme versus first year of elementary-education programme). The research is quantitative with a quasi-experimental design. To assess the understanding of NOS in students' science teachers, an adapted version of the VNOS-D + instrument was applied before and after the intervention. Both groups received three NOS teaching sessions using History of Science as context and implementing an explicit and reflective instructional strategy, centered on students. The main results of this study indicate that both groups significantly improved their understanding of NOS, and in the same magnitude, after the intervention. In addition, the understanding of some of the aspects of NOS improved more easily than others. Finally, there is a discussion about the contribution of this study to the pre-service science teacher's education.

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Nature of science; NOS; science teacher training; pre-service science teachers

Introduction

An adequate understanding of Nature of Science (NOS) is a critical component for scientific literacy and one of the greater goals of science education (Bencze et al., 2020; Höttecke & Allchin, 2020; McComas, 2020a; Osborne et al., 2003). Despite the existence of worldwide agreement on the importance of NOS for scientific literacy, numerous research indicates that most science teachers and students do not possess an adequate understanding of it (e.g. Cofré et al., 2019; McComas, 2020a; Murphy et al., 2021; Zion et al., 2020). In the same way, many studies about the understanding of NOS have demonstrated that explicit and reflective instruction, over implicit teaching, seems to be the most effective focus to improve their understanding (Cofré et al.,

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2019; Lederman, 2007; McComas et al., 2020). On the other hand, there is abundant empirical evidence that supports that some strategies, such as inquiry, practical work combined with reflection, and some curricular elements such as socio-scientific topics and History of Science seem to be effective in the teaching of NOS (Cofré et al., 2019; McComas et al., 2020). However, there are no studies that directly evaluate if disciplinary knowledge in science contributes or not to the understanding of NOS. Although it seems there is not a minimum of scientific disciplinary knowledge necessary to learn NOS, since this can be learned by students in kindergarten (e.g. Akerson & Donnelly, 2010; Hansson et al., 2020), there are very few studies that compare learning of groups of students with different disciplinary knowledges. Therefore, the goal of this study was to evaluate the level of understanding of NOS in preservice teachers from an Elementary Education programme and from Secondary (Biology) Education programme – with different disciplinary training in sciences – before and after the same intervention that included three lessons contextualised in History of Science (HOS thereafter).

Theoretical framework

NOS conceptualisation

Some scholars (e.g. Bell et al., 2001) recognise that the conceptualisation of the NOS in science education was first discussed in 1907 (Central Association of Science and Mathematics Teachers, 1909). Since then, a large body of literature has developed related to the teaching and learning about NOS (e.g. Cooley & Klopfer, 1963; Mackay, 1971; Lederman & Druger, 1985; Mead & Metraux, 1957; Robinson, 1965; Rubba & Andersen, 1978; see also Bell et al., 2001 for a twentieth-century bibliography collection, and Lederman, 1992 for a detailed review of some of the most important studies from 1950 to 1990). Since the first studies in the second half of the twentieth century, researchers generated instruments to evaluate specific aspects or topics related to the NOS. For example, Cooley and Klopfer (1963) applied to 2808 high school students the Test on Understanding Science (TOUS) instrument, which measure understandings about (1) the scientific enterprise, (2) scientists, and (3) the methods and aims of science. After TOUS, the Nature of Scientific Knowledge Scale (NSKS) was developed (Rubba, 1976) and administered to teachers and students (e.g. Lederman & Druger, 1985; Rubba & Andersen, 1978) with the aim of assessing six aspects of nature of scientific knowledge: (1) amoral, (2) creative, (3) evolutionary, (4) parsimonious, (5) testable, and (6) unified.

Thus, both the empirical research as well as the theoretical proposals developed in the following two decades generated a diversity of instruments (e.g. VOSTS [Views on Science Technology Society] [Aikenhead, & Ryan, 1992], VNOS [Views of Nature of Science Questionnaire] [Lederman et al., 2002] or SUSSI [Student Understanding of Science and Scientific Inquiry] [Liang et al., 2009]), and conceptualisations of what aspects or elements are involved in understanding NOS (e.g. Lederman, 2007; McComas, 1996; Mulvey & Bell, 2017; Osborne et al., 2003). Some authors defined NOS understanding as simple as to know how science works (e.g. Clough, 2011), but others refer to the epistemology of science, science as a way of knowing, and the values and beliefs inherent to scientific knowledge (Abd-El-Khalick & Lederman, 2000;

Lederman, 1992). However, the science education research community identified several aspects of NOS that appear to be teachable and learnable in school (e.g. Lederman et al., 2002; McComas, 1996; Mulvey & Bell, 2017; Osborne et al., 2003; Smith et al., 1997; Southerland et al., 2006). This conceptualisation has been referred to as the 'general aspects' conceptualisation of NOS (Kampourakis, 2016) or as the 'consensus view' (McComas, 2020b). According to this 'educational' view, there are some general NOS aspects (usually between seven and ten, depending on the authors) that can effectively be taught in the school context. The main objective of this conceptualisation is to address students' alternative conceptions of how science works and what scientific knowledge is.

Almost since its inception, this conceptualisation has been criticised as insufficient and misleading, and different alternative approaches have been proposed (e.g. Allchin, 2011; Alter, 1997; García-Carmona & Acevedo-Díaz, 2017; Hodson & Wong, 2017; Irzik & Nola, 2011; Matthews, 2012; van Dijk, 2011). For example, Hodson and Wong (2017) argue for the need of a philosophically more sophisticated NOS model, which is in harmony with the contemporary scientific practice and that authentically exposes students to the diversity of scientific sub-disciplines. Allchin (2011) argues for the need of broader perspectives on NOS. He proposes 'whole science' and maintains that NOS in school science should be sensitive to all dimensions of the scientific practice. He proposed that many aspects related to science as an enterprise – funding, motivation, peer review, fraud, and others – need to be emphasised for learners. Irzik and Nola (2011) criticise the 'general aspects' frameworks of NOS not only, for portraying a narrow image of science and provide a uniform view of science and not being sensitive to the differences among scientific disciplines; but also, by lacking systematic unity. The family resemblance approach (FRA) (Irzik & Nola, 2011), which attempted to overcome these problems relies on the idea that even if there are some characteristics common to all sciences, these characteristics cannot be used to define science itself. The authors suggested four specific categories that are open-ended: (a) processes of inquiry, (b) aims and values, (c) methods and methodological rule, and (d) products. Although they claim that the family resemblance approach can capture the dynamic and open-ended NOS much better than the 'general aspects' view, it is also clear that it would be a much more complex approach to implement in the school context (Erduran & Dagher, 2014).

Although most of the proposals criticising the 'general aspects' view have been theoretical in nature (e.g. Allchin, 2011; Irzik & Nola, 2011; Matthews, 2012), in recent years empirical studies have begun to be conducted using the FRA model which will bring greater diversity to research on NOS (e.g. Akgun & Kaya, 2020; Çilekrenkli & Kaya, 2022; Cullinane & Erduran, 2022; Erduran & Kaya, 2018; Erduran et al., 2021; Peters-Burton et al., 2019). For example, in a year-long study with two pre-service science teachers, Cullinane and Erduran (2022) showed that, after attending a 6-week NOS workshops using the 'Reconceptualized FRA-to-NOS (RFN)' framework (Kaya & Erduran, 2016), the course has a positive influence on teachers' knowledge about NOS, but one of them have still difficulty incorporating NOS understanding into her lesson plans during her practicum experience (see also Cheung & Erduran, 2022, for a review about empirical studies using FRA).

Although we acknowledge the multiple competing ways to conceptualise NOS for K-12, in the current study NOS was conceptualised as 'general aspect', as advocated by Kampourakis (2016) and used in many recent studies (e.g. Edgerly et al., 2022; Erumit & Akerson, 2022; Hansson et al., 2020; Khishfe, 2022; Mesci, 2020; Yacoubian, 2021).

Teaching NOS in an explicit, reflective, and historical manner

Regarding effective instruction of NOS, a large amount of empirical data generated in recent decades suggests that explicit and reflective way of teaching NOS as the most effective method (e.g. Abd-El-Khalick & Lederman, 2000; Bell et al., 2011; Lederman, 2007; McComas et al., 2020). More specifically, recent literature reviews suggested that there are four commonly used instructional settings for teaching NOS, history of science, socioscientific issues, argumentation, and inquiry (Cofré et al., 2019; McComas et al., 2020).

History of Science (HOS) addresses scientific knowledge in connection to its historical and social context, and it is possible to observe the controversies in it as an essential scenario of the scientific practice, clarifying and associating to the characteristics of NOS (Adúriz-Bravo & Izquierdo-Aymerich, 2009; Allchin, 2013; McComas et al., 2020). At the same time, the teaching of NOS using HOS allows to provide examples of the development of scientific theories, get to know the relationships between science and society in each age, illustrate the universal and multicultural NOS, among others (Allchin, 2011; Allchin et al., 2014). In fact, several studies have demonstrated that HOS is a useful and relevant curricular component to include in the instruction of NOS since it established a concrete connection between the contents that must be taught and the social and scientific context in which this knowledge was created (e.g. García-Carmona, 2018; García-Carmona & Acevedo-Díaz, 2017; Pavez et al., 2016; William & Rudge, 2019). In this way, interventions that use HOS consider a diversity of strategies and activities that are contextualised or hyper-contextualised, including historical discoveries, historical narratives, disputes and scientific errors, classic experiments, and the development of scientific theories (e.g. Cofré et al., 2018; Dai et al., 2021; García-Carmona, 2018; Nyarko & Rudge, 2022; Pavez et al., 2016; William & Rudge, 2019). On the other hand, HOS is an instructional context often used to the teaching of NOS in pre-service teacher programme s (e.g. García-Carmona, 2018; McDonald, 2010; Nouri & McComas, 2021; Rudge et al., 2014; Seung et al., 2009). For example, García-Carmona (2018) showed that, based on the critical and reflexive reading of the historical case of Rosalind Franklin and the elucidation of the molecular structure of DNA, pre-service elementary teachers improved their understanding of the different NOS aspects addressed in the study, giving more importance to non-epistemic than to epistemic element of NOS.

Understanding of NOS in elementary and secondary science pre-service teachers

More than a decade ago, the need to strengthen training of science teachers in NOS at all educational levels has become evident, both in initial training as well as with in-service teachers, since most of the research carried out has clearly shown that science teachers at

different educational levels do not have, in general, a good understanding of NOS (Bell et al., 2016; Cofré et al., 2019; Lederman, 2007; Mesci, 2020; Mulvey et al., 2016; Mulvey & Bell, 2017; Murphy et al., 2021; Zion et al., 2020). This difficulty of understanding may be since, according to some authors, the understanding of NOS is a meta-learning process that requires the acquisition of metacognitive abilities, since it is connected to a way of understanding how knowledge is built, and in which the student plays an active role and is aware of their own learning (Abd-El-Khalick & Akerson, 2004; 2009). On the other hand, according to Mesci and Schwartz (2017), many of these efforts to improve conceptions about NOS in pre-service teachers have had limited success, since there is more difficult to understand certain aspects of NOS than others.

However, very few is knowing about what traits of pre-service teachers is related with their learning about NOS. For example, after a detailed analysis of 16 studies of pre-service science teachers, Cofré et al. (2019) found that usually pre-service elementary and secondary teachers held naïve views about the relationship between theory and law and the plurality of scientific method at the beginning of the studies while their most informed views were the empirical and creative nature of NOS (see also Krell et al., 2015). But the same analysis showed that the improvement after instruction is not the same in elementary and secondary teachers (Cofré et al., 2019). The conclusion of this review state that, 'future research could include comparisons of NOS learning between pre-service teachers who had different types of scientific knowledge before the intervention (e.g. earth sciences vs. biology or elementary teachers vs. secondary teachers)'. However, subsequent studies in pre-service science teachers usually had focused on elementary teachers (e.g. Erduran et al., 2021; García-Carmona, 2018; Mesci, 2020) or secondary science teachers (e.g. Aragón-Méndez et al., 2019; Bell et al., 2016; Cullinane & Erduran, 2022; García-Carmona & Acevedo-Díaz, 2017; Reinisch & Krüger, 2018), but not in comparing both groups. A notable exception is the study of Krell et al. (2015) which studied elementary and secondary pre-service teachers' understanding of NOS in Germany. In this study, the understanding of six aspects of NOS (all include in the 'general aspect view') were assessed using a quantitative instrument of 28 closed items. The sample included an intervention group who participated in a STEM curriculum with an explicit and reflective NOS instruction ($N = 76$ elementary teachers), and three control groups, students who did not partake in the new curriculum ($N = 134$ elementary teachers; $N = 198$ secondary science teachers, and $N = 161$ no-science teachers). Although, unfortunately, the NOS understandings of primary and secondary science teachers were not compared, comparisons were made that shed light on the topic of interest. Secondary science teachers do not have a more informed view than secondary non-science teachers. On the other hand, primary teachers with explicit and reflective teaching do improve their understanding of NOS compared to the group without this intervention. However, there is also a temporal effect on the understanding of NOS, as teachers in their final year of study present better views than those in their initial years.

From this complex scenario, the need emerges to continue researching about the understanding of NOS in pre-service science teachers, focusing on isolating the factors that have an impact on building the process of understanding in future science teachers, such as the previous scientific knowledge that they have.

Research questions

Considering the total evidence mentioned, the question that concerns us is whether science disciplinary training of pre-service teachers could (or not) be one of the factors that could influence their understanding of NOS. In this context and to guide this study, the following research questions have been generated:

1) What is the level of understanding of NOS in pre-service teachers with different disciplinary training before and after an intervention?
2) Does science disciplinary training received by pre-service biology teachers have an impact in the understanding of NOS in contrast to pre-service elementary teachers with no science disciplinary training?
3) What aspects of NOS are the most naïve and informed in pre-service teachers with different disciplinary training before and after an intervention?
4) How did the understanding of the different aspects of NOS change after the intervention?

Methodology

Design

The research presents a quantitative approach and a quasi-experimental design. This design included two experimental groups of the same university, corresponding to pre-service teachers from an Elementary Education programme (from years 1 to 6), and from a Secondary Biology education programme (from years 7 to 12) with a different previous science disciplinary training, who received three NOS teaching sessions contextualised in HOS. The implemented instructional method was explicit, reflective, and student-centred.

Participants and initial science education context

Compulsory schooling in the country comprises 8 years of basic or elementary education (ages 6–13) and 4 years of secondary education (ages 14–17). Almost all programme s of initial science teacher education have concurrent instruction; that is to say, teachers in training take courses both on pedagogy and on the discipline during their 4 or 5 years of instruction (Cofré et al., 2015, 2022). The programme s for elementary and secondary pre-service science teachers differ significantly. Elementary pre-service teacher programme s typically require not more than two courses about natural science and one science method course, because teachers must be prepared to teach other content areas. However, many universities include a minor in science and usually have between three and six courses about natural sciences and two science methods courses. Secondary science teacher programme s include more extensive education in one or two scientific subjects (typically more than 15 courses in 4 or 5 years) and between 2 and 5 science methods courses (typically two courses) (Cofré et al., 2015, 2022).

Participants of the study were 21 first-year pre-service teachers from an Elementary Education programme, taking a course about: 'Scientific Knowledge' and 12 s-year pre-service teachers from a Secondary biology education programme taking the course: 'History of Biology'. Both classes include the same teaching of NOS based in HOS, named 'Intervention of NOS' or simply 'Intervention'. On the other hand, it is important to clarify that at the time of receiving the intervention, pre-service biology teachers had six classes taken, considered for purposes of this study, as previous science disciplinary training. These classes were (i) Fundamental Biology, (ii) Mathematics, (iii) General Chemistry, (iv) Cellular Biology, (v) Plant Biology, (vi) Physics, and (vii) Organic Chemistry. The teacher in charge of teaching both courses was an expert science educator, with a vast and known trajectory as a science educator and researcher in the teaching of NOS. Finally, all students that participated in this research did so in an informed and voluntary way and signed a consent before the research began.

NOS intervention

The intervention consisted of three lessons of 180 min each, carried out during a month, where the following aspects of NOS were incorporated in an explicit way: (i) its empirical nature, (ii) its constant reviewing or tentativeness, (iii) the contribution of creativity and imagination, (iv) its subjective nature, (v) the difference between observation and inference, and (vi) its social and cultural context, where the teaching emphasis of each aspect during the intervention was equivalent.

In this intervention HOS was used as a teaching strategy, based on the proposals of Rudge and Howe (2009). It included various NOS activities with or without context (Clough, 2011) and an argumentation activity. As a way of ensuring comparability between both groups, the intervention was carried out by the same science educator and was characterised for a student-centred approach, for which the same planning, activities, and supplies were designed and applied, such as worksheet, research articles, readings, videos, and supporting material. The intervention structure included, in the first session, a review of the case of resistance to malaria and sickle-shaped heterozygous from the review of the work of Allison (2002). In this session, the main aspects developed were empirical, creative, and subjective. In the second session, a description was made of the discovery of the HIV virus and the beginnings of immunology, based on the 'AIDS in 1988' article by Gallo and Montanier (1988) and on the 'Beyond love' book by Lapierre (1991). The aspects of NOS that were discussed in this session were the difference between observation and inference and the sociocultural dimension of science. In the third session work was carried out based on the topic of the development of the Chromosomal Theory of Inheritance, based mainly on the article about Morgan and the origins of modern genetics by Allen (2015), and using historical (e.g. A history of genetics, Sturtevant [1965]) and biological (Griffiths et al., 2008) books. The aspect of NOS that was discussed mainly in this session was tentativeness. The most extensive description of each one of the sessions is found in Pavez et al. (2016).

Instruments and data collection

The instrument used to evaluate the understanding of NOS in pre-service teacher was a reduced version of the VNOS-D+ questionnaire (Views of Nature of Science), (VNOS thereafter), developed by Lederman et al. (2002). Although this instrument has been criticised for being poorly contextualised, and do not assess NOS in a more applied way that connects to scientific literacy (Allchin, 2011), it is important to highlight that VNOS is one of the most used in NOS literature (Abd-El-Khalick, 2014; Cofré et al., 2019), and it is still used profusely in current studies (e.g. Mesci, 2020; Peters-Burton et al., 2019; Wang et al., 2022; Zion et al., 2020). Participants answered the questionnaire before and after the intervention, which was applied during 60 min in the classroom. The questionnaire was answered individually and in paper-and-pencil format. Later, these were fully transcribed and digitalised. The questionnaire was comprised by a subgroup of the total questions of VNOS-D+, this is, six open questions which aimed to assess the understanding of six of the seven aspects of NOS, only missing the aspect of the difference between theory and law (Cofré et al., 2014). From the questionnaire, two of the authors of this research evaluated the answers of students, assigning them one of the three categories to each of the aspects considered here. These categories were: informed view, naïve view, and mixed view. The categorisation of the answers in 'informed view', 'naïve view' or 'mixed view' was performed based on the rubric used in Pavez et al. (2016).

Data analysis

Students considered were those that responded to the VNOS-D+ questionnaire both before and after the intervention, which reduced the final number of students assessed by this study. Of the total 23 elementary education student teachers, 21 answered the pre and post VNOS. Meanwhile, out of a total of 17 Biology student teachers, 12 answered both instruments.

Data analysis for this questionnaire implied the creation of a profile for each participant according to their understanding of NOS and, according to the current literature, three levels of understanding for each student answer in relation to each of the six studied aspects of NOS (Cofré et al., 2014; Lederman et al., 2002; Pavez et al., 2016). When an answer clearly demonstrated that the opinion of the student about the specific characteristic was aligned with the recommended opinion, the answer was coded as 'informed' (assigning a value of 2). Whereas, if the answer was aligned with the recommended position, but it was not fully developed or described or it was simply an iteration of a proportioned definition, it was coded as 'mixed' (assigning a value of 1). If the answer demonstrated that the vision of the student was not aligned to the established description, the answer was coded as 'naïve' (assigning a value of 0). The answers were coded independently according to the criteria of the used rubric. Subsequently, the two researchers in charge of the previous coding met and discussed each score to come to an agreement. A 96% agreement was recorded between the review of both researchers and the total number of disagreements were settled with a third researcher. To generate a quantitative analysis, along to the qualitative description of the profile of each student, the variable of

NOS values was created. This reflects the understanding of NOS through the sum of the obtained value for each one of the studied aspects in each student. Therefore, since the studied aspects were 6, and the value range assigned to the understanding of NOS is between 0 and 2, the quantitative profile of each student could fluctuate between 0 and 12 points. In addition, to calculate the change in the understanding of NOS after the intervention, we obtained the difference between the values of the quantitative profile of each student after and before the intervention. This was calculated through the subtraction of the NOS values obtained in the pre-test to the NOS values obtained in the post test. The 'difference in understanding of NOS' variable could fluctuate from 0 to 12 points. Thus, the study attempted to give a holistic quantitative perspective of the change in understanding of NOS, as well as a view of the change in understanding of NOS by each aspect. This type of analysis has already been done before for these purposes (e.g. Cofré et al., 2017, 2018).

Statistical analysis

Initially, the distribution of each data group was analysed through the statistical test of Shapiro–Wilk. Since 4 of the 6 data groups did not have a normal distribution, non-parametric statistical tests were used to compare the groups. To compare the different groups, the Mann–Withney test was used. To compare the same groups before and after the teaching the Wilcoxon test was used. To evaluate the understanding of each aspect of NOS before and after the intervention in both groups of pre-service teachers, the percentage of participants in each group that displayed a naïve, mixed, and informed level of understanding of NOS was calculated. After this, the Mc Nemar statistical analysis was carried out to evaluate the significance of change by aspect. For the total of the performed analyses, differences with $p < 0.05$ were considered significant. Statistical tests were carried out in the SPSS, version 22.0 programme.

Results

Understanding of NOS before and after the intervention

According to the Wilcoxon test, significant differences were obtained between the values of the VNOS-D + questionnaire in the pre and post-tests, both for pre-service elementary teachers ($z = -3{,}73$; $p < 0{,}001$; $r = 0.81$), and for pre-service biology teachers ($z = -2{,}42$; $p < 0.05$; $r = 0.67$). In addition, according to the Mann-Withney test significant differences were obtained both in the understanding of NOS between programme s before the intervention ($z = -3.97$; $p < 0{,}001$; $r = 0.69$), as well after the intervention ($z = -3{,}54$; $p < 0{,}001$; $r = 0.61$) (Figure 1). Furthermore, according to the Mann-Withney test, when comparing the difference between the NOS values before and after the intervention between the two programme s there is no significant difference between both groups ($z = -0.50$; $p = 0.61$; $r = 0.09$).

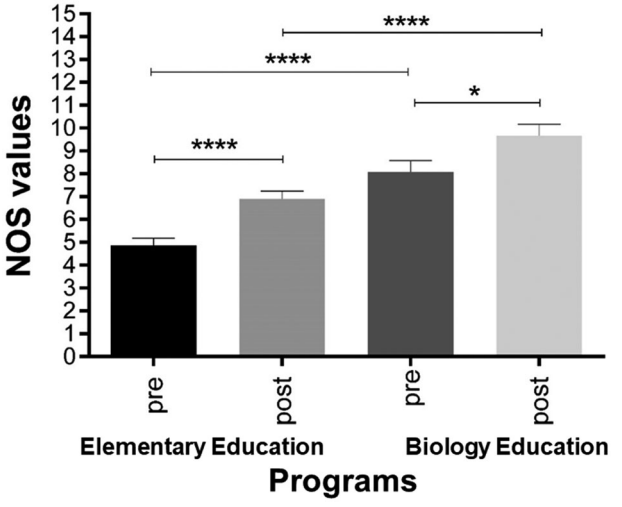

Figure 1. The graph shows the averages of NOS values (with their respective standard error bars) obtained in the pre and post- test of the pre-service teachers of first year at Elementary Education programme and of pre-service teachers of second year at Biology Education programme. * $p < 0.05$; *** $p < 0.001$.

Understanding of each aspect of NOS evaluated before and after the intervention

With the purpose of evaluating this objective, we determined the percentage of participants of each group that presented a level of understanding of NOS in the naïve, mixed, and informed categories for each aspect of NOS, analysed before and after the intervention. It is worth noting that all aspects improved after the intervention in preservice elementary teachers, however, significant change was seen in the aspects of tentativeness,

Table 1. Percentage of pre-service teachers in each of the categories of NOS understanding for each aspect.

NOS Aspects	Naive (%)		Mix (%)		Informed (%)	
	Pre	Post	Pre	Post	Pre	Post
(A) Elementary pre-service teachers						
Tentative (*)	**24**	**0**	71	81	**5**	**19**
Empirical	5	0	14	0	81	100
Observation/Inference (*)	**76**	**38**	**19**	**48**	5	14
Subjective	43	24	33	33	24	43
Creative	14	9	81	81	5	10
Sociocultural (*)	**76**	**33**	**19**	**57**	5	10
(B) Biology pre-service teachers						
Tentative	0	0	50	50	50	50
Empirical	8	8	0	8	92	84
Observation/Inference (*)	**42**	**16**	8	17	**50**	**67**
Subjective (*)	**33**	**8**	**25**	**9**	**42**	**83**
Creative	0	0	83	50	17	50
Sociocultural (*)	8	8	**42**	**25**	**50**	**67**

Notes: The bold type highlights the values in which there were significant differences from each category for each aspect of NOS (*). (A) Elementary pre-service teachers, and (B). Biology pre-service teachers. Analysis of statistical significance of the Mc Nemar test confirmed these observations.

observation/inference and sociocultural, while the aspects that presented less improvement after the intervention were the empirical, subjectivity, and creativity (Table 1). In the same way, in the case of pre-service biology teachers, the aspects that improved after the intervention were observation/inference, subjectivity and sociocultural, while those that improved less after the intervention were tentativeness, empirical, and creativity (Table 1). Table 2 shows examples of participants' responses of four specific NOS aspects in the pre- and post-test for both groups (elementary and secondary pre-service teachers).

Discussion

It was obtained from the study that the explicit and reflective intervention based on HOS was successful since it helped to achieve significant improvement in the understanding of NOS both, elementary and biology pre-service teachers. These findings agree with the results of several previous studies (e.g. Akerson et al., 2009; 2010; Akerson & Abd-el-Khalick, 2003; Clough, 2011; Erduran et al., 2021; García-Carmona, 2018; Krell et al., 2015; Mesci, 2020; Murphy et al., 2021; Reinisch & Krüger, 2018). In addition, the results of this research agree with the observations of various studies that suggest that the use of HOS improves the understanding of NOS (e.g. Cofré et al., 2014; García-Carmona, 2018; García-Carmona & Acevedo-Díaz, 2017; Nouri & McComas, 2021; Paraskevopoulou & Koliopoulos, 2011; Pavez et al., 2016; Rudge et al., 2014; Rudge & Howe, 2009). On the other hand, no differences were found between the groups of this study, since both improved their understanding of NOS. Therefore, it could be said that in this case an effect of previous disciplinary science training was not observed regarding the understanding of NOS, after the intervention in both groups of pre-service teachers. A similar result have been reported by Krell et al. (2015), when they compared pre-service teachers' understanding of NOS between two groups with different disciplinary knowledge (science and non-science secondary). However, we did find a difference in NOS understanding previously the intervention, with pre-service biology teachers being much more informed at the beginning of the study than pre-service elementary teachers.

A hypothetical explanation for this could be that developing content-knowledge seems to come along with gain some NOS knowledge. This proposal agrees with the findings of Krell et al. (2015) who showed a positive effect of semester level on NOS views for a group of pre-service secondary teachers. Alternatively, a choice of career in biology teaching (instead of choosing teaching at elementary level) could reflect interests that support getting NOS knowledge outside formal education. Although these hypotheses seems to run counter to the strong empirical evidence on the effectiveness of explicit and reflective NOS instruction (e.g. Lederman, 2007; McComas et al., 2020), it is important highlight that, this study showed that only three lessons of an effective NOS instruction brought pre-service elementary teachers to the same level that pre-service biology teachers achieved in one year of science content instruction.

In relation to the understanding of NOS of each of the six aspects evaluated in this study (tentativeness, empirical, observation/inference, subjectivity, creativity, and sociocultural aspect), it can be observed that both groups of pre-service teachers had informed views of empirical and creative nature of NOS at the beginning of the study, such as

Table 2. Illustrative quotes of elementary and biology pre-service teachers that changes her/his NOS understanding from naïve or mixed (pre-intervention) to mixed or informed (post-intervention) on four aspects of NOS.

NOS aspect	Pre-service elementary teachers	Pre-service biology teachers
Tentativeness		
	Scientists try to prove theories and postulates empirically, so I don't think it can change, but I think it could be transformed into knowledge that can go further with other convictions. (pre-test S1, Naïve)	Knowledge can change with the future because science is subjective, so technological advances plus new studies could change previous knowledge. (pre-test S2, Mixed)
	Before I was not completely sure weather knowledge can vary and change in relation to time or scientist who studies a subject. However, now I am sure that it is possible. (post-test S1, Mixed)	Yes, I believe that knowledge can change because there are still things that have not been tested and many that, in my opinion, have not yet been discovered. In addition, technology and advances allow change in knowledge. For example, a few years ago, there was no cure for certain types of cancer, however knowledge has changed over time and today there are more effective forms and possible cures for certain types of cancer. (post-test S2, Informed)
Observation / inference		
	There is a possibility that they [scientist] have a misconception of their appearance. However, based on their evidence, I could say that they can be 50% certain. (pre-test S3, Mixed)	They can't be sure because no one was there, only sketches can be made based on the fossils collected. (pre-test S5, Naïve)
	Probably not 100% sure, but they can be certain based on the studies and analyses carried out, so models that could represent the appearance of the dinosaurs are made. (post-test S3, Informed)	Scientists do not have complete clarity on the subject, they can only rely on the evidence collected and the models that seem most convincing to them according to the fossil record they have. (post-test S5, Informed)
Sociocultural		
	It must be universal because it reflects the knowledge of planet earth in general and involves us only as the individuals that we are as citizens of planet earth and the universe. (pre-test S7, Naïve)	I believe that science could permeated with cultural and social values, which provides a degree of subjectivity. It depends on the context in which it is done. (pre-test S6, Mixed)
	Science is pressured by culture, I mean, by political and social values, philosophical beliefs, and intellectual norms of the culture in which it is practiced. (post-test S7, Informed)	Science is a construct of knowledge created by men who are immersed in a social context, in a context of beliefs and intellectual norms, which influences the moment of generating this knowledge. (post-test S6, Informed)
Subjectivity		
	Because there are many theories and possible ways how they [dinosaurs] became extinct. Each discovery leads to a new finding from which a new theory can be developed. (Student 11, Mixed)	Only theories can be proposed about how the extinction occurred, but no statement can be made because no one was there to corroborate. (Student 8, Naïve)
	Although they all have the same information, different hypotheses can be generated about how they became extinct, depending on the experience of each scientist. (Student 11, Informed)	I think they don't agree as science is subjective, so a variety of opinions are acceptable. Furthermore, if everyone thought the same way, knowledge would stagnate and there would be no more progress. (Student 8, Informed)

literature describe (e.g. Cofré et al., 2019; Krell et al., 2015). On the other hand, both groups also showed naïve views on two other NOS aspects (observation/inference and

sociocultural) before the intervention, but pre-service teachers' understanding improved significantly after instruction, which agrees partially with previous observations (e.g. Cofré et al., 2019; García-Carmona, 2018; Mesci, 2020). Usually, other aspects that improve after instruction are tentativeness and subjectivity (e.g. Mesci, 2020; Erduran et al., 2021). However, in this study, tentativeness improved significatively only in elementary teachers, and subjectivity only in biology teachers. In elementary teachers, the study of García-Carmona (2018), showed that participants ($N = 42$) improved their understanding of four NOS aspects addressed based on reading of an historical case, especially, the understanding of social and cultural aspects. On the other hand, Mesci (2020) showed that pre-service middle school teachers ($N = 39$) improved their view of seven NOS aspect, after participated in a History and Nature of Science course. Some of the aspect that showed a higher improvement were, tentativeness, Socio/cultural and subjectivity. Finally, Erduran et al. (2021), studied the changes of pre-service science teachers' NOS perceptions after a decontextualised discussion session about NOS in two different national contexts: Turkey and England. The finding suggested that pre-service teachers improve their views about the tentativeness of scientific knowledge and about the social and institutional dimensions of NOS.

In summary, from an educational point of view, our results and those presented in the literature suggest that the sociocultural elements of science, as well as tentativeness and subjectivity are aspects that can be improved in a short period of time if effective instruction such as HOS is applied. However, there may be differential improvement behaviours depending on the disciplinary knowledge of the trainee teachers.

Limitations

Because this study did not include a control group it would be inadequate to ascribe the change in understanding of NOS of participants only to the intervention focus provided in this programme. In addition, consideration must be made of the generic limitations of working in research with individuals as subjects of study, where it is not feasible to control all the variables that influence obtaining pure data. In this context the small size of the sample leads us to be cautious when declaring its implications. Finally, we also recognise as a limitation that we have chosen to work only with six aspects of the consensus view of NOS (e.g. Kampourakis, 2016; McComas, 2020b), as this makes it more complex to be able to compare our results with current studies using other aspects (e.g. Theory and law, 'the scientific method') or different approaches such as FRA (e.g. Cheung & Erduran, 2022) or those proposed by Spanish researchers (e.g. García-Carmona & Acevedo-Díaz, 2017).

Implications and future research

According to what is reported in this present research, we believe it would be important to continue to carry out this type of research at university level, in scientific training programme s, such as in students of sciences bachelor's degrees (scientists in training) and in pre-service teachers of sciences different than biology. It would also be very interesting to perform a true longitudinal study with similar groups to determine how the new understanding of science is being formed in future science teachers. Finally, it is important to

continue these kinds of studies and determine whether certain aspects of NOS exist that are developed in a different way depending on disciplinary knowledge (e.g. epistemic vs non-epistemic), or in different instructional contexts (HOS vs. other strategies) (Cofré et al., 2019; McComas et al., 2020).

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Ethical statement

The P. Universidad Católica de Valparaíso research bioethics committee board approved the research procedures included in the projects 1131029 and 1211920.

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