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How to assess and categorize teachers' views of science?
Two methodological issues

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Abstract
This paper addresses two methodological issues related to the assessment of teachers' views of science. The first concerns the distinction between the "nature of science" (NOS) and the nature of "scientific inquiry" (SI): should the points related to NOS and those related to SI be analyzed independently? The second concerns the categorization of teachers' views: is it relevant to analyze them according to a grid of predefined epistemological conceptions? Alternatively, does an empirical approach allow the emergence of epistemological profiles with an overall consistency? To investigate these issues, an empirical study has been performed based on a questionnaire on teachers' views of science (called the "VOS questionnaire") which has been submitted to 160 in-service primary teachers. With respect to the first issue, the analysis of the outcomes brings to light implicative relations between teachers' views on NOS-type items and their views on SI-type items. This calls into question the alleged necessity of separating NOS and SI when assessing teachers' epistemology. Concerning the second issue, a multiple correspondence analysis leads us to identify clusters of teachers with various levels of expertise concerning different epistemological points and without an overall consistency from the point of view of philosophy of science. This suggests that teachers' consistency has to be found not in their view of science taken in isolation but considered in combination with other kinds of knowledge (e.g., pedagogical content knowledge) and their practices of science teaching.

Keywords: nature of science, scientific inquiry, philosophy of science, teacher knowledge

1. Introduction: two methodological issues

Students' understanding of the "nature of science" (NOS) has been advocated as an "essential part of any science education" (National Research Council, 2012, p. 78): it is assumed to raise students' interest in science, to facilitate learning of science content, and to favor informed decision-making on socioscientific issues (Hodson, 2014). To improve students' understanding of NOS, "explicit" epistemological discussions guided by the teachers about various aspects of science seem to constitute the most efficient approach (Akerson & Volrich, 2006). In this regard, a necessary condition for teachers to be able to implement such an approach is that they hold themselves an informed view of science (Lederman, 2007). This is the first reason why research related to NOS in science education has been concerned with the assessment of teachers' views of science. Another reason is that teachers' view of science is part of a whole set of beliefs and knowledge which might affect their teaching practices, or be affected by them (Guerra-Ramos, 2012; Waters-Adams, 2006). A better understanding of these complex relationships may be of interest in building more efficient training programs for teachers (Anderson, 2015).

The very question of how to assess teachers' views of science has been investigated for several decades. In particular, there has been extensive discussion on the epistemological points that should be assessed (Allchin, 2011; Hodson, 2014; Kelly, 2014; Lederman et al., 2002; Matthews, 2012; McComas, 1998). Some authors (Lederman et al., 2002; McComas, 1998) have put forward a set of consensual epistemological points which deserve to be studied in the frame of science teaching: for example, the empirical nature of scientific knowledge, its tentativeness, the fact it is theory-laden, or its social and cultural embeddedness. Others have argued against such a list of epistemological points: it may suggest a static picture of science (Allchin, 2011; Hodson, 2014; Matthews, 2012), and it does not acknowledge the differences between sciences (Hodson, 2014; Kelly, 2014). Alternatively, some authors have stressed the importance of considering teachers' perspectives to determine more accurately which specific epistemological points are appropriate to be introduced at each educational stage (Leden et al., 2017; Leden & Hansson, 2019). There has been also discussion on the methods for gathering data: on the advantages and inconveniencies of questionnaires, interviews and classroom observations, and of closed and open-ended questions (for a review of these points, see Lederman, 2007).

However, there has been minimal discussion to date on the methods for analyzing the data gathered when asking teachers questions concerning the nature of science. In this paper, we would like to draw attention to two important methodological issues in this regard. The first one concerns the distinction between the "nature of science" (NOS) and the nature of "scientific inquiry" (SI). This distinction has been put forward by Lederman and their colleagues (Lederman, 2007; Lederman et al., 2002, 2014). They explain what they mean with these expressions as follows: "Nature of science (NOS) embodies what makes science different from other disciplines such as history or religion. NOS refers to the characteristics of scientific knowledge that are necessarily derived from how knowledge is developed […]. Scientific inquiry (SI) is the process of how scientists do their work and how the resulting scientific knowledge is generated and accepted" (Lederman et al., 2014, p. 66). While acknowledging there is interdependency between NOS and SI, they consider these two aspects of science should be clearly distinguished: "The conflation of NOS and scientific inquiry has plagued research on NOS from the beginning" (Lederman, 2007, p. 835). Note that this distinction between NOS and SI is based on a restricted definition of NOS, according to which this expression refers merely to the characteristics of stabilized scientific knowledge. Other authors understand the expression "nature of science" with a broader meaning which encompasses also reference to the methods and processes of constructing scientific knowledge (Clough, 2011; Hodson, 2014)). Let us here examine NOS in its restricted definition and assume this construct to be conceptually distinct from SI. This distinction has recently been supported by an empirical study carried out by Neumann, Neumann and Nehm (2011) with a sample of undergraduate science majors: a statistical analysis of the participants' views on various points concerning either NOS or SI tends to show that these two constructs are two separate dimensions. A methodological question comes up: should the points related to NOS and those related to SI be analyzed independently? As a matter of fact, the Ledermans' and their colleagues have developed two distinct questionnaires: the "VNOS" questionnaire intended to assess teachers' and students' views on NOS (Lederman et al., 2002) and the "VASI" questionnaire designed to assess their views on SI (Lederman et al., 2014). Should teachers' answers to each of these questionnaires be clearly distinguished or is it worthwhile to combine both analyses?

The second methodological issue concerns the categorization of teachers' views of science. A possible approach, which may be called "normative," consists in analyzing teachers' view according to a grid of predefined epistemological conceptions, namely those supported or challenged by philosophers of science, such as empiricism, inductivism, instrumentalism, relativism, or realism. Such an approach, although marginal, has been applied for instance by Kang et al. (2005) or Park and Lee (2009). This approach raises questions. We may wonder what it means for a teacher to have, for instance, an instrumentalist view of science: is she/he aware of it? Does she/he have a stable and coherent instrumentalist view, that is, which holds for every model and theory, whatever the domain under consideration? Some empirical studies are challenging this idea (Guerra-Ramos, 2012). As emphasized by Nott and

Wellington (1996), teachers are not "professional" philosophers of science; they do not aim at studying scientific activities and build a global and coherent conception of science. As a consequence, it seems disputable to interpret teachers' views of science in terms of the well-defined epistemological conceptions endorsed by the philosophers of science. Alternatively, several researchers like Lederman and their colleagues (2002, 2014) have proposed to characterize teachers' views of science by distinguishing a set of epistemological points and assessing their levels of expertise on each of these points taken in isolation. Such an approach, as a matter of fact, is not subject to the former objection. No global a priori categorization is applied to teachers' views of science. This approach is partly empirical: it allows for the emergence of new epistemological profiles on the basis of teachers' views on a whole set of points. Considering the fact teachers are not professional philosophers of science, a new question then arises: do teachers' epistemological profiles, identified with such an empirical approach, correspond to epistemological conceptions with an overall consistency?

In this paper, we present an empirical study designed to investigate both methodological issues. Our research questions can be recalled as follows:

(1) To what extent does the combined analysis of teachers' views on NOS and SI enable a deeper understanding of their view of science?
(2) To what extent do teachers' epistemological profiles, identified by means of an empirical approach, correspond to epistemological conceptions with an overall consistency?

To study these two questions, we built a questionnaire including questions on NOS and SI and submitted it to 160 in-service primary teachers. In the following sections, we will first present the epistemological points we chose to assess by means of our questionnaire, before describing the methods for building the questionnaire, for coding teachers' answers, and for validating the questionnaire. We will then present the outcomes gathered with our sample of in-service primary teachers and discuss their implications with respect to both research questions.

2. Selecting a set of epistemological points to be assessed

The VNOS and the VASI questionnaires are two meaningful and valid tools allowing assessing teachers' views respectively on NOS and SI. In particular, the VNOS questionnaire has been used in the frame of numerous studies, either relative to NOS instruction in the classrooms or relative to teachers' training on NOS. Accordingly, these two questionnaires seem to be suited tools to investigate the first research question, that is, to assess teachers' views on NOS and their views on SI before looking for possible relations.

However, when taking a closer look at the epistemological points assessed by VNOS and VASI (Tables 1 and 2), some of these points appear to be very similar.

NOS1: The empirical nature of scientific knowledge
NOS2: Observation, inference and theoretical entities in science
NOS3: Scientific theories and laws
NOS4: The creative and imaginative nature of scientific knowledge
NOS5: The theory-laden nature of scientific knowledge
NOS6: The social and cultural embeddedness of scientific knowledge
NOS7: Myth of the scientific method
NOS8: The tentative nature of scientific knowledge

Table 1. The epistemological points assessed by VNOS (Lederman et al., 2002)

SI1: Scientific investigations all begin with a question but do not necessarily test a hypothesis SI2: There is no single set and sequence of steps followed in all scientific investigations SI3: Inquiry procedures are guided by the question asked SI4: All scientists performing the same procedures may not obtain the same results SI5: Inquiry procedures can influence the results SI6: Research conclusions must be consistent with the data collected SI7: Scientific data is not the same as scientific evidence SI8: Explanations are developed from a combination of collected data and what is already known

Table 2. The epistemological points assessed by VASI (Lederman et al., 2014)

Consider first SI6, which states that "research conclusions must be consistent with the data collected." This amounts to saying that the construction of scientific knowledge needs to take account of the observations or experiments that have been performed on the subject under study. In this respect, SI6 can be viewed as a specific statement of NOS1, namely "the empirical nature of scientific knowledge." Note that Lederman and colleagues make very similar statements when explaining the content of NOS1 and SI6: concerning NOS1, they write that "science is at least partially based on observation of the natural world" (2002, p. 499); concerning SI6, they explain that "scientific knowledge is empirically based" (2014, p. 70).

Let us look now at SI4, which states that "all scientists performing the same procedures may not get the same results." A possible explanation of this point is that scientists may interpret the data in the frame of different theoretical frameworks, as Lederman and colleagues emphasize: "Students need to understand that scientific data do not stand alone, can be interpreted in various ways, and 'that scientists may legitimately come to different interpretations of the same data'" (2014, p. 69). This point can be viewed as a direct consequence of NOS5, that is, "the theory-laden nature of scientific knowledge."

The similarity between both questionnaires can also be found in the case of NOS7 and SI2. NOS7, the "myth of the scientific method," is described by Lederman and colleagues as "the belief that there is a recipe-like stepwise procedure that all scientists follow when they do science" (2002, p. 501). This is precisely what is disputed by SI2, which states, "There is no single set and sequence of steps followed in all scientific investigations."

The design of VNOS and VASI as two distinct questionnaires was motivated by the alleged necessity of making a clear distinction between NOS and SI. Paradoxically, these questionnaires do not manage to isolate two independent sets of epistemological points. To some extent, the sets of points which are investigated by means of the two questionnaires are overlapping. This shows how difficult it is to make a sharp distinction between the points related to NOS and those related to SI.

Besides this overlap problem, the choice of the epistemological points made for the VNOS questionnaire has been challenged by several authors (Allchin, 2011; Hodson, 2014; Matthews, 2012): some of these points are disputable from the point of view of philosophy of science, other appear to be too subtle and not essential in the context of NOS education, while several important epistemological points are missing. As a consequence, although we decided to take the VNOS and VASI questionnaires as a starting point of our study, we examined and revised the two sets of epistemological points associated to them (see Tables 1 and 2): we avoided the overlap problem by putting aside redundant points (NOS1 being redundant to some extent with SI6, as well as NOS5 with SI4, and NOS7 with SI2); we discarded those which are disputable from the point of view of philosophy of science (NOS3 and NOS4) or which are not essential in the NOS education context (SI5 and SI7); and added several points considered by philosophers of science as depicting essential aspects of science among which three are consensual (i.e., scientists develop models that are distinct from the empirical reality; errors may play a constructive role in the development of science; interactions between scientists actively contributet to the construction and validation of scientific knowledge) and two controversial (i.e., realism *versus* instrumentalism with respect to the role of models; relativism or rejection of relativism concerning the influence of the socio-economic and cultural context on the construction of scientific knowledge). Eventually, we selected eleven points (see Table 3; for details on the selection process of these points, see Online resource 1).

Each point is described as referring either to NOS or to SI based on the following criteria: the point under consideration refers to NOS if it concerns the status of knowledge which is already produced and stabilized; the point refers to SI if it concerns the process of developing new knowledge, which therefore is not completely produced and stabilized yet.

VOS 1	Scientific knowledge is based on empirical support	NOS
VOS 2	There is no single scientific method	SI
VOS 3	Scientific investigations are motivated and guided by questions and problems	SI
VOS 4	Scientific knowledge is always tentative	NOS
VOS 5	Science interacts with the socio-economic and cultural context	SI
VOS 6	The empirical data on which scientific knowledge is based are always theory-laden	NOS
VOS 7	The models built by the scientists are distinct from the empirical reality	NOS
VOS 8	Errors may play a constructive role in the development of science	SI
VOS 9	Interactions between scientists actively contribute to the construction and validation of scientific knowledge	SI
VOS 10	Realism *versus* instrumentalism with respect to the role of models	NOS
VOS 11	Relativism or rejection of relativism concerning the influence of the socio-economic and cultural context on the construction of scientific knowledge	SI

Table 3. The epistemological points selected for the VOS questionnaire

3. Methods

Since we chose a new set of epistemological points, we also had to build a new questionnaire, which we labelled the “VOS questionnaire” (VOS for “View Of Science”). Let us present the method for building and validating it.

3.1 Choosing the kinds of questions

This questionnaire was developed in the frame of the research project FORMSCIENCES. Some of the choices made during the construction of this questionnaire resulted from two constraints of the project: the number of teachers involved in the project (over 150) and limited time for answering the questions (between 20 and 30 min). Accordingly, we had to develop a questionnaire to identify the views of science of a large number of teachers in a very short time. We chose to combine open-ended and closed questions. Open-ended questions allow teachers to answer freely on concrete cases; they are assumed to provide a more in-depth understanding of their individual views of science on some points. Closed questions ensure a better rate of answers and are faster to answer and easier to analyze. Note that many studies have brought to light several recurrent answers concerning teachers’ views of science so that the state-of-the-art is sufficiently developed to legitimate closed questions on some points. Besides, we included both general and context-specific questions (atomism, astronomy). Each question of the VOS questionnaire provides information for either one or two epistemological points. Conversely, the epistemological points are examined by means of one, two or three questions.

The VOS questionnaire includes 9 questions, some with sub-questions. The relations between the questions and the VOS items are described in Table 4.

Question	Type of question	Assessed epistemological points
Q1	closed-ended	VOS6
Q2	open-ended	VOS1, VOS4 and VOS7
Q3	closed-ended	VOS2 and VOS 3
Q4	closed-ended	VOS2
Q5	1st part: closed-ended 2nd part: open-ended	VOS8
Q6	1st part: closed-ended 2nd part: open-ended	VOS9
Q7	closed-ended	VOS5 and VOS11
Q8a	closed-ended	VOS5 and VOS11
Q8b	closed-ended	VOS5
Q9a	closed-ended	VOS4, VOS7 and VOS10
Q9b	closed-ended	VOS1 and VOS9

Table 4. The VOS items assessed by the questions of the VOS questionnaire

We present two examples below (the complete questionnaire can be found in Online resource 2). The first example is a context-specific open-ended question dealing with atomism. This question (combined with other questions) is intended to assess teachers' views on two points: reference to empirical support and the role of models.

Q2. Some philosophers in Ancient Greece proposed to describe matter as consisting of atoms. This description was later abandoned for several centuries. A description in terms of atoms was eventually endorsed by scientists at the beginning of the 20th century.
What are the possible reasons, according to you, to explain why this description was accepted at the beginning of the 20th century? Note that no scientific and/or historical knowledge is required to answer this question.

The second example is a context-dependent closed question that intends (with other questions) to assess teachers' views on several points: reference to empirical support, tentativeness of scientific knowledge, and the role of models.

Q9. (A) In ancient times, Greeks thought that the Sun turned around the Earth (geocentric description). We believe today that it is the Earth that turns around the Sun (heliocentric description).
With which one of the following claims do you agree the most (only one possible choice):

- □ The geocentric and heliocentric descriptions are both models that aim to describe the world, but the heliocentric model is closer to reality.
- □ The geocentric and heliocentric descriptions are both models that enable the explanation and prediction of observable phenomena, but the heliocentric model enables the explanation and prediction of more observable phenomena.
- □ The geocentric description is only a model, whereas the heliocentric description is in line with reality.
- □ None. In this case, explain why:

3.2 Method for coding the answers

For each epistemological point, the participant's answers are examined in light of several possible views, either in line with expert views of philosophers of science or in line with novice views indicated in previous empirical studies (Abd-El-Khalick, 2001; Cobern & Loving, 2002; Lederman, 2007; Windschitl, 2004). For the consensual points, the participant's view is then coded as "novice," "rather novice," "rather expert," "expert," or "depending on the context." For the two controversial points, a specific coding is proposed.

We describe the coding method for one epistemological point, namely for VOS1: "the construction of scientific knowledge is based on empirical support" (for the other points, see Online resource 3). The respondent's view on this point is inferred from her/his answers to Q2 and Q9B. In the case of Q2 (which is related to atomism), we distinguish three possible answers: (a) answer with no reference to experience; (b) answer associated with naïve realism (i.e., with reference to experience but without the idea that the atomist description is a model and with the idea that experience can verify or reject with certainty the atomist description); (c) answer associated with balanced empiricism (i.e., with reference to experience and with the idea that the atomist description is a model, and/or fulfills an explicative or predictive functions, and/or is a tentative description of matter). In the case of Q9B (which is related to the geo- and heliocentric representations), we distinguish three possible answers: (a) answer associated with naïve empiricism (at least answer #2); (b) answer associated with balanced empiricism (answer #1 or answers #1 and #3); (c) answer not interpretable in terms of naïve or balanced empiricism (answer #3). The view of the respondent concerning VOS1 is then coded as follows: "novice" if {Q2: a or b} and {Q9B: a}, "rather novice" if ({Q2: a or b} and {Q9B: c or NA}) or ({Q2: NA} and {Q9B: a}), "rather expert" if {Q2: c} and {Q9B: c or NA}, "expert" if {Q2: c} and {Q9B: b}, "depending on the context" if ({Q2: a or b} and {Q9B: b}) or ({Q2: c} and {Q9B: a}).

3.3 Validity of the questionnaire

To ensure that teachers did not assign a different meaning to the words of the questions, the latter was first discussed with 3 in-service teachers during interviews with an average duration of 1 h. We modified some terms that were ambiguous and could be misinterpreted by teachers. A new version of the VOS questionnaire was submitted to 24 pre-service primary teachers during a course session that aimed to introduce some key ideas of philosophy of science. A collective discussion was conducted to ensure good understanding of the questions and to propose some supplementary modifications of formulations.

We then submitted this questionnaire to 10 experts in the field of philosophy of science and science education. For the consensual epistemological points, at least 8/10 of these respondents were identified as being "expert" or "rather expert." This result confirms that the assessed points are indeed consensual among experts and provide validation of the questionnaire.

3.4 Participants

We administered the VOS questionnaire to a sample of 160 in-service primary teachers, mostly female (~ 70%), coming from 4 different regions of France, and teaching in grades 3, 4, or 5. Their average declared time for teaching science in their classrooms was approximately 1.3 h per week. They had been teaching in primary school for 16 years on average (with an average age of 47 years old). Approximately 40% of them had a degree in science.

3.5 Reliability of the coding process

To ensure reliability of the coding process for the open-ended questions, every answer from the 160 teachers was analyzed either by two or three researchers simultaneously. For each answer, the researchers first performed their own analysis before checking whether they agreed on the coding. In case of disagreement, these answers were discussed collectively until agreement and confidence on the coding were reached. Moreover, we presented the coding method to a researcher external to the project, with expertise in philosophy of science. He coded the answers of 20 teachers randomly chosen among our sample. A high degree of interrater agreement (86%) was obtained.

4. Outcomes

We first provide the distribution of teachers' views for each epistemological point. We then present the outcomes of a statistical analysis intended first to determine if teachers' views on NOS-type items and their views on SI-type items are independent or not, and second to investigate the overall consistency of teachers' epistemology.

4.1 Distribution for each epistemological point

The distribution of teachers' views for each VOS item is given in Table 5.

	VOS1	VOS2	VOS3	VOS4	VOS5	VOS6	VOS7	VOS8	VOS9
Novice	25	10	9	14	0	42	51	5	1
Rather Novice	55	32	*na*	32	0	*na*	*na*	41	36
Rather Expert	5	38	*na*	20	47	*na*	39	1	18
Expert	0	20	91	2	53	58	1	50	2
Context dependent	8	*na*	*na*	11	*na*	*na*	5	*na*	25
No answer	1	1	0	21	0	0	5	3	19
Answer not Interpretable	6	*na*	*na*	*na*	*na*	*na*	*na*	0	0

("na" stands for "not applicable")

	VOS10
Naive Realist	51
Balanced Realist	15
Instrumentalist	28
No answer	6

	VOS11
Strong relativist	8
Rather strong relativist	49
Rather moderate relativist	14
Moderate relativist	20
Rejection of relativism	0
No answer	8

Table 5. Distribution of teachers' views for each VOS item in terms of percentages

Concerning most consensual epistemological points, we observe that teachers' views are distributed in a relatively balanced way between novice and expert views. Concerning one point, VOS1, most teachers are (rather) novice. On the contrary, concerning two points, VOS3 and VOS5, most teachers are (rather) experts.

We note also that a significant proportion of teachers provide answers depending on the context under consideration: the views of some teachers on VOS1, VOS4, VOS7, and VOS9 differ if the context is related to the atomist description or to the geo- and heliocentric descriptions.

Considering the two controversial epistemological points, we observe that half of teachers are naïve realists with respect to the role of models (VOS10), while the others are either balanced realist or instrumentalist on this point. It appears also that more than half of teachers are (rather) strong relativist with regard to the influence of the socio-economic and cultural context on the construction of scientific knowledge (VOS11).

4.2 Statistical analysis

To further analyze the teachers' answers to the VOS questionnaire, we performed a statistical analysis of the data. To avoid circularity in the outcomes of this analysis, we combined items VOS 4, 7, and 10, which are associated with the same series of questions, into a unique indicator called VOS "Model." These items were submitted to a multiple correspondence analysis with hierarchical clustering on principal components (Greenacre & Blasius, 2006). The results show that teachers' answers can be assembled into four clusters, labelled Models 1, 2, 3, and 4, which correspond to four levels of expertise: from less expert (Model 1) to most expert (Model 4).

We then performed an implicative statistical analysis (Gras et al., 1998), which allows answering the following question: given two binary variables *a* and *b* within a given population *E*, what is the measure according to which "if *a* is true" then "*b* is also true"? (Figure 1).

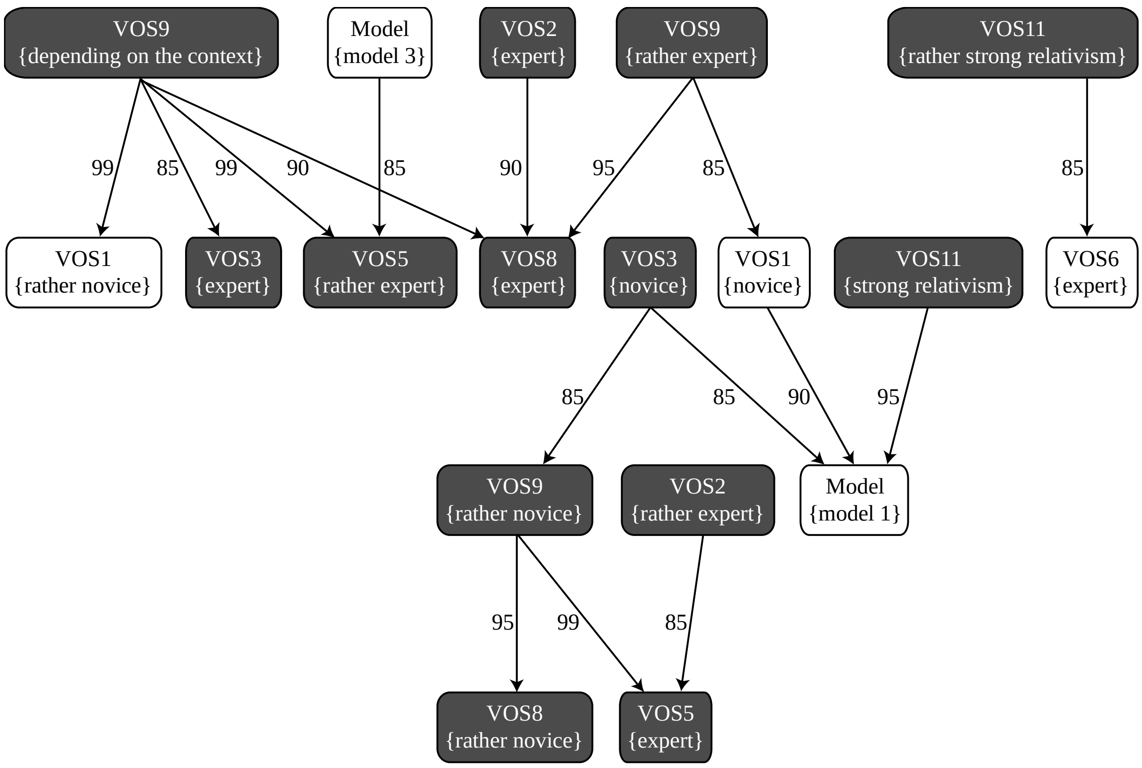

Figure 1. Implicative graph displaying relations between teachers' views on the VOS-items.
The numbers corresponds to a measure of implication.
White bubbles are NOS-type items, and black bubbles are SI-type items.

This statistical analysis brings to light several relations between NOS-type items and SI-type items. For instance, we can observe implications between Model (NOS-type item), on the one side, and VOS3 or VOS5 (both SI-type items), on the other side. Likewise, there is an implication between VOS6 (NOS-type item) and VOS11 (SI-type item). More precisely, teachers who believe that the socio-economic and cultural context has a strong influence on the construction of scientific knowledge are likely to acknowledge the theory-ladenness of empirical data. Such an implication, which is meaningful from the point of view of philosophy of science, could not have been identified if NOS and SI were not assessed and analyzed jointly.

It is also noteworthy that VOS6 and VOS11, which appear here to be linked statistically, are consensual and controversial epistemological points, respectively. This result shows the potential insight that questions on controversial aspects of science might provide to understand teachers' views of science.

Besides, we observe implications between some of the items which display a consistency in terms of the level of expertise. For instance, teachers who are *rather expert* concerning the nature and role of models are very likely to be *rather expert* concerning the interactions between science and the socio-economic and cultural context; or teachers who are *novice* concerning the nature of questions and problems are very likely to be *novice* concerning the nature and role of models. However, the results also show that some teachers can answer as experts concerning one item but as novices concerning another item. For example, teachers who are rather expert on VOS 9 are very likely to be novice on VOS 1, and teachers who are rather novice on VOS 9 are very likely to be expert on VOS 5. This last example may appear incoherent to some extent from the point of view of philosophy of science. Indeed, both VOS5 and VOS9 refer to a social dimension of the development of science, even though these social dimensions do not lie at the same level (VOS5 being at the level of the global interaction between science and society, whereas VOS 9 being at the level of the social interactions between scientists). This part of the results argues against a consistency within teachers' views of science from a strictly epistemological point of view.

5. Discussion

Let us consider our first research question 1: to what extent the combined analysis of teachers' views on NOS and SI enables a deeper understanding of their view of science? A preliminary remark concerns the questionnaires designed to asses these points: it appears that the sets of epistemological points assessed by the VNOS and VASI questionnaires (designed by Lederman and colleagues) are overlapping to some extent; in other words, it is difficult in practice to draw a sharp distinction between the points related to NOS and those related to SI. Beyond this conceptual difficulty, the statistical analysis of our data gathered with in-service primary teachers reveal the existence of several relations between their views on NOS and their views on SI. For instance, teachers who consider that the construction of scientific knowledge is strongly influenced by the socio-economic and cultural context (SI-type item) also tend to view the empirical data as theory-laden (NOS-type item). This calls into question the alleged necessity of separating NOS and SI when assessing teachers' epistemology. Furthermore, some of the relations identified empirically appear meaningful from the point of view of philosophy of science. This can be explained by the close relation, emphasized by Hodson (2014), between the nature of scientific knowledge and the methods for constructing this knowledge. As a consequence, our results show that assessing and analyzing teachers' views jointly on NOS-type and SI-type items may favor a deeper understanding of teachers' views of science.

The outcomes of this empirical study also shed light on the second research question: teachers' views of science, taken globally, cannot be located on a scale of expertise nor can they be associated with well-defined profiles with an inner consistency from the point of view of philosophy of science. As Guerra-Ramos (2012, p. 648) puts it: "generally speaking, [teachers] hold eclectic or mixed views which do not mirror consistently a single particular view or a particular philosophical position."

For all that, teachers are not incoherent individuals. Recall that they are not "professional" philosophers of science (Nott and Wellington, 1996); they do not aim at developing a global and consistent conception of science for itself; they are concerned primarily with science teaching, and that, in various domains which are possibly disconnected. Consistency might therefore be found not in teachers' views of science taken in isolation but in their views of science considered in association with their teaching practices, and accordingly with other kinds of knowledge required for teaching, such as subject matter knowledge or pedagogical content knowledge (Shulman, 1986). In this regard, another interesting outcome of our study is that teachers' views on some VOS items appear to be context dependent. For instance, for some teachers, their view on the nature of models is different when considering either the atomist model or the heliocentric model. Note that the atoms which are microscopic elements of matter can never be observed directly, unlike the Earth and the Sun which are macroscopic and hence observable systems. This ontological difference between the systems of both models may influence teachers' answers. Another part of the explanation of the context-dependency might be the fact that many primary teachers of our study are used to teach the heliocentric model in their classrooms (in accordance with the official curriculum), which is not the case regarding the atomist model. Accordingly, this outcome suggests that teachers' views of science are situated to some extent in their teaching practices. This finding provides support for the idea of a mutual influence between teachers' views of science and their teaching practices, as suggested by former studies (Guerra-Ramos, 2012; Waters-Adams, 2006).

In light of these outcomes, we argue for an assessment method of teachers' views of science which combines a *theoretical approach* that makes use of the literature in philosophy of science to identify a whole set of possible epistemological points related both to NOS and SI, and an *empirical approach* that allows the emergence of possibly unexpected epistemological profiles for which the consistency must be considered in relation to the teaching practices and to other knowledge. We believe that this relationship is complex and difficult to grasp and therefore requires investigation using a qualitative and contextualized approach. Shedding light on this complex relationship and the ways it is built might be of great interest for improving teachers' training programs by making them more suited to both teachers' current knowledge and practices.

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Electronic supplementary material

Online resource 1: Selection process of epistemological points for the VOS questionnaire
Online resource 2: The questions of the VOS questionnaire
Online resource 3: The coding method of the VOS questionnaire

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Online resource 1
Selection process of epistemological points for the VOS questionnaire

The epistemological points of the VOS questionnaire were selected as follows: we examined the two sets of epistemological points associated to the VNOS and VASI questionnaires and avoided the overlap problem by putting aside redundant points; we discarded those which are disputable from the point of view of philosophy of science or which are not essential in the NOS education context; and added several points considered by philosophers of science as depicting essential aspects of science and put forward by some researchers in the NOS literature.

From the set of epistemological points associated to the VNOS and VASI questionnaires, we maintained the six following points: “scientific knowledge is based on empirical support” (VOS1) which is identical to NOS1; “there is no single scientific method” (VOS2) which is similar both to NOS7 and SI2; “scientific investigations are motivated and guided by questions and problems” (VOS3) which is similar to SI3 and refers partly to SI1; “scientific knowledge is always tentative” (VOS4) which is identical to NOS8; “science interacts with the socio-economic and cultural context” (VOS5) which is similar to NOS6; “The empirical data on which scientific knowledge is based are always theory-laden” (VOS6) which is similar to NOS5 and may be related to SI4 (see above).

We did not maintain two points of VNOS (NOS3 and NOS4) because we considered them as disputable from the point of view of philosophy of science. NOS3 puts forward a distinction between “scientific theories and laws,” which is based on the definition of laws as “descriptive statements of relationships among observable phenomena” (Lederman et al., 2002, p. 500). However, this definition holds merely for *phenomenological laws*, such as Boyle’s law mentioned by Lederman and colleagues, but not for *theoretical laws* (Cartwright, 1983), that is, laws with a wider scope that are the result of a more theoretical reasoning and are only indirectly related to experience (e.g., Newton’s laws of motion or Schrödinger’s equation). Such laws may constitute the core of a theory. Hence, for such laws, it seems difficult to make a strong distinction between laws and theories. The second disputable point concerns “creativity” (NOS4), presented as a feature of science contrasting with “rationality” (Lederman et al., 2002, p. 500). Some usual kinds of *reasoning* in science have a creative power, such as analogical reasoning (Hofstadter & Sander, 2013). Making an analogy, which amounts to describe new phenomena by referring to well-established knowledge, may be considered as a rational process. This type of creativity in science cannot be opposed so easily to rationality. Therefore, we did not select these two points in our questionnaire.

We discarded two points of VASI (SI5 and SI7), because we considered them as too subtle and specific in the context of NOS education. SI5 states that “inquiry procedures can influence the results,” what can be related to an idea emphasized by the philosophers of science belonging to the new experimentalism movement: the instruments used by scientists do not merely test theories but have an active role insofar as they determine the way we interact with the world and because they may produce new phenomena (Hacking, 1983, Pickering, 1995). Even if the acknowledgement of this idea was as an important step in the field of philosophy of science, it seems quite difficult to make sense of it in the context of science education. According to SI7, “scientific data are not the same as scientific evidence.” Although scientific evidence may imply some further interpretation not implied in the scientific data, both of them are to some extent theory-laden. In this regard, the difference between data and evidence is quite subtle.

Besides, in line with Allchin (2011), Hodson (2014), Matthews (2012), we chose to include five other epistemological points which correspond to essential aspects of science.

These points may be of importance with respect to NOS education and are possibly relevant for investigating the relationships between teachers' views of science and their science teaching practices. Three of them are consensual in philosophy of science. The first point concerns the nature of models which recently have drawn much attention both in philosophy of science (Frigg & Hartmann, 2018; Hesse, 2000; Varenne, 2013) and science education (Gobert et al., 2011; Gogolin & Krüger, 2018). Among the various epistemological aspects of models, we chose to assess the following one: "Scientists develop models that are distinct from the empirical reality" (VOS7). Note that this point can be viewed as a specific instance of NOS2. It seems worthwhile that the various models studied in science teaching are not taken by students as mere copies of the empirical reality (Harrison & Treagust, 2000), but identified as intellectual constructs which can be empirically tested and may be revised or replaced by new models (Gilbert, 2004).

The second point concerns the role of errors: "Errors may play a constructive role in the development of science" (VOS8). This point has first been emphasized by Bachelard (2004 [1938]) who described the advancement of science as a constantly renewed process of identification of errors within the current knowledge and "rectification" of these errors. Similarly, Kuhn (1970) has provided many examples of new theories (e.g., quantum mechanics) of which the development has been stimulated by "anomalies" (e.g., the dark body spectrum) identified in the frame of former theories. More recently, Kipnis (2011) and Allchin (2012) have stressed that errors deserve to be studied with students since they are natural and unavoidable part of scientific process: in particular, they display the "variety of ways for scientific development" (Kipnis, 2011, p. 681), and "convey the tentativeness of science" (Allchin, 2012, p. 906).

A third point, which has been studied in depth in sociology and philosophy of science but which is missing in VNOS and VASI, concerns the role of the interactions between the scientists: "Interactions between scientists actively contribute to the construction and validation of scientific knowledge" (VOS9). Without considering in details the complex process of social interactions between scientists as brought to light both by sociologists and philosophers of science (Longino, 2016; Pestre, 2006), we refer here to the practices of construction and validation of new knowledge based on argumentation, evaluation and critique which are developed in the frame of oral or written interactions between scientists (Duschl et Osborne, 2002; Jiménez-Aleixandre & Crujeiras, 2017; Kelly, 2014).

The nine points formulated above are consensual in the field of philosophy of science. Following the suggestion of Matthews (2012) and Hodson (2014), we propose to include two other points which concern controversial aspects of philosophy of science. Recall that in our study we are looking for the consistency of teachers' views of science; in this regard, we can wonder if their views on controversial points might not be instructive. This deserves to be tested by means of our questionnaire. We chose two controversial aspects which are related to the former epistemological points. The first one (VOS10) concerns the role of models and brings into opposition the two following views: the models aim at describing the world (realist view of models); or they aim at explaining and predicting observable phenomena (antirealist or instrumentalist view of models) (Frigg & Hartmann, 2018; Hesse, 2000; Varenne, 2013). The second one (VOS11) develops the question of the interaction between science and the socio-economic and cultural context (VOS5): does this context have an influence on the construction of scientific knowledge (e.g., on the formulation of a scientific hypothesis or on the interpretation of an empirical outcome) (Longino, 2016; Pestre, 2006)? On this question, one may support or reject a "(strong) relativist" view.

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Online resource 2
The questions of the VOS questionnaire

Q1. Two groups of scientists dealing with the same question gather the same data. Do you think they will come to the same conclusions?

- □ No, not necessarily, because in some cases the data are not sufficient. But with complementary data, the scientists would come to the same conclusions.
- □ Yes, because if the data are the same, the scientists must come to the same conclusions.
- □ No, not necessarily, because however large the set of data may be, there are always several possible conclusions.
- □ I don't know.

Q2. Some philosophers in Ancient Greece proposed to describe matter as consisting of atoms. This description was later abandoned for several centuries. A description in terms of atoms was eventually endorsed by scientists at the beginning of the 20th century.
What are the possible reasons, according to you, to explain why this description was accepted at the beginning of the 20th century? Note that no scientific and/or historical knowledge is required to answer this question.

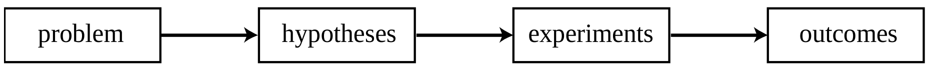
Q3. Do you think a scientific approach involves:

	always	often	sometimes	never	I don't know
emitting hypotheses	□	□	□	□	□
measurements	□	□	□	□	□
a preliminary step of observation	□	□	□	□	□
the statement of a problem	□	□	□	□	□
tests of hypotheses	□	□	□	□	□
building a model	□	□	□	□	□
an analysis of the current works	□	□	□	□	□
data processing	□	□	□	□	□
a theoretical construction	□	□	□	□	□
experiments	□	□	□	□	□
computer-assisted simulations	□	□	□	□	□
asking questions	□	□	□	□	□

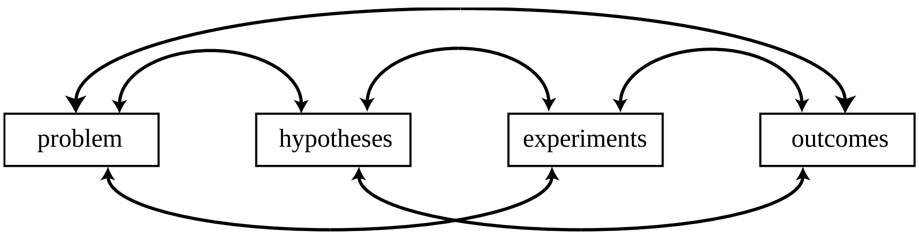
Q4. Ideally, an experimental approach is closer to approach 1 or 2?

to approach 1	□
to approach 2	□
there is no ideal experimental approach	□
I don't know	□

Approach 1:



Approach 2:



Q5. Some ideas and theories have been put aside throughout history (e.g., the idea that Earth has the shape of a plate, that spermatozoids entail tiny human beings already formed, that bleeding makes fever decrease…). Do you think that these ideas and theories have contributed to the development of knowledge?

always	often	sometimes	never	I don’t know
□	□	□	□	□

Explain your answer. You can provide one or two examples.

Q6. According to you, with respect to the development of science, interactions between scientists are:

very important	important	not so important	not important	I don’t know
□	□	□	□	□

Why?

Q7. According to you, scientific researches are dependent on the socio-economic and cultural context?

no	yes, a little	yes, strongly	I don’t know
□	□	□	□

If yes, is it:

sometimes	often	always
□	□	□

Q8. (A) According to you, on which aspects of research can the socio-economic and cultural context have an influence?

	yes	no	I don’t know
on the choice of the topics being investigated	□	□	□
on the interpretation of the outcomes	□	□	□
on the allocation of human and financial resources	□	□	□
on the choice of the hypotheses	□	□	□

other:

(B) According to you, what are the socio-economic and cultural aspects that can have an influence on research?

	yes	no	I don’t know
financial	□	□	□
political	□	□	□
intellectual currents (religions, philosophical conceptions…)	□	□	□

other:

Q9. (A) In ancient times, Greeks thought that the Sun turned around the Earth (geocentric description). We believe today that it is the Earth that turns around the Sun (heliocentric description).
With which one of the following claims do you agree the most (only one possible choice):

□ The geocentric and heliocentric descriptions are both models that aim to describe the world, but the heliocentric model is closer to reality.
□ The geocentric and heliocentric descriptions are both models that enable the explanation and prediction of observable phenomena, but the heliocentric model enables the explanation and prediction of more observable phenomena.
□ The geocentric description is only a model, whereas the heliocentric description is in line with reality.
□ None. In this case, explain why:

(B) The geocentric description has been abandoned because (you can check one or several answers):

□ it is unable to account for some phenomena in a simple manner.
□ it has been shown to be false.
□ Copernicus and Galileo brought new ideas.
□ other

Online resource 3
The coding method of the VOS questionnaire

The epistemological point	The questions and their possible answers			The possible inferred views
VOS1 Scientific knowledge is based on empirical support	Q2: (a) answer with no reference to experience (b) answer associated to naïve realism (i.e., with reference to experience, but without the idea that the atomist description is a model, and with the idea that experience can verify or reject with certainty the atomist description) (c) answer associated to balanced empiricism (i.e., with reference to experience, and with the idea that the atomist description: is a model, and/or fulfils an explicative or predictive functions, and/or is a tentative description of matter)	Q9B: (a) answer associated to naïve empiricism (at least answer #2) (b) answer associated to balanced empiricism (answer #1, or answers #1 and #3) (c) answer not interpretable in terms of naïve or balanced empiricism (answer #3)		- *novice* if {Q2: a or b} and {Q9B: a} - *rather novice* if ({Q2: a or b} and {Q9B: c or NA}) or ({Q2: NA} and {Q9B: a}) - *rather expert* if {Q2: c} and {Q9B: c or NA} - *expert* if {Q2: c} and {Q9B: b} - *depending on the context* if ({Q2: a or b} and {Q9B: b}) or ({Q2: c} and {Q9B: a}) - *NI* if {Q2: NA} and {Q9B: b or c} [NA = No Answer; NI = Not Interpretable]
VOS2 There is no single scientific method	Q3: (a) answer suggesting the respondent is unaware of the diversity of the kinds of investigations and believes that making science always involves experimentation (“always” is checked for “measurements” and/or “experiments”) (b) answer suggesting the respondent is or may be aware of the diversity of the kinds of investigations (“always” is checked neither for “measurements” nor for “experiments”)	Q3': (a) answer associated to naïve inductivism, i.e., suggesting the respondent believes in the primacy of observation (“always” is checked for “a preliminary step of observation”) (b) answer suggesting the respondent is not endorsing naïve inductivism (“always” is not checked for “a preliminary step of observation”)	Q4: (a) answer suggesting the respondent believes that making science amounts to follow a well-defined and ordered set of steps (answer #1) (b) answer suggesting the respondent acknowledges that scientists can follow various sets and orders of steps (answer #2 or #3) (c) answer #4 (I don’t know)	- *novice* if answer (a) to all three questions - *rather novice* if (answer two times (a) and one time (b), NA or (c) to the set of questions Q3, Q3' and Q4) or (answer one time (a) and one time (b) and one time NA or (c) to the set of questions Q3, Q3' and Q4) - *rather expert* if answer one time (a), NA or (c) and two times (b) to the set of questions Q3, Q3' and Q4 - *expert* if answer (b) to all three questions - *NA*
VOS 3 Scientific investigations are motivated and guided by questions and problems	Q3": (a) answer suggesting the respondent is unaware of the role of questions and problems in science (“always” is not checked neither for “the statement of a problem” nor for “asking questions”) (b) answer suggesting the respondent is aware of the role of questions and problems in science (“always” is checked for “the statement of a problem” and/or for “asking questions”)			- *novice* if {Q3": a} - *expert* if {Q3": b} - *NA*

<table>
<tr>
<td>VOS4
Scientific knowledge is always tentative</td>
<td colspan="3">Q2':
(a) answer suggesting the respondent believes that the atomist description has been proven definitively, and/or especially that experience can verify with certainty the atomist description (e.g., with the use of words like “verify,” “prove,” or “demonstrate”)
(b) answer suggesting the respondent is aware of tentativeness of the atomist description, and/or especially of the limited role of experience (e.g., with the use of words like “support,” or “corroborate”)</td>
<td colspan="3">Q9A:
(a) answer suggesting the respondent believes that the heliocentric description has been proven to be true (answer #3)
(b) answer suggesting the respondent is aware of the tentativeness of the heliocentric description (answer #1 or #2)
(c) answer #4 (None)</td>
<td>- novice if {Q2': a} and {Q9A: a}
- rather novice if ({Q2': a} and {Q9A: c or NA}) or ({Q2': NA or NI} and {Q9A: a})
- rather expert if ({Q2': b} and {Q9A: c or NA}) or ({Q2': NA or NI} and {Q9A: b})
- expert if {Q2': b} and {Q9A: b}
- depending on the context if ({Q2': a} and {Q9A: b}) or ({Q2': b} and {Q9A: a})
- NA</td>
</tr>
<tr>
<td>VOS5
Science interacts with the socio-economic and cultural context</td>
<td colspan="2">Q7:
(a) answer suggesting the respondent is unaware of the interaction between science and society (answer “no” or “I don’t know”)
(b) answer suggesting the respondent is aware of this interaction (answer “yes, a little” or “yes, strongly”)</td>
<td colspan="2">Q8A:
(a) answer suggesting the respondent is unaware or hardly aware of the kinds of interactions that may exist between science and society (answer “no” or “I don’t know” for every item, or “yes” to only one item)
(b) answer suggesting the respondent is aware of the kinds of interactions that may exist between science and society (answer “yes” at least for two items)</td>
<td colspan="2">Q8B:
(a) answer suggesting the respondent is unaware of the kinds of interactions that may exist between science and society (answers “no” or “I don’t know” for every item)
(b) answer suggesting the respondent is aware of the kinds of interactions that may exist between science and society (answer “yes” at least for one item)</td>
<td>- novice if answer (a) to all three questions
- rather novice if answer (a) to one or two among the three questions
- rather expert if answer (b) to one or two of three questions and NA to the other(s)
- expert if answer (b) to all three questions
- NA</td>
</tr>
<tr>
<td>VOS6
The empirical data on which scientific knowledge is based are always theory-laden</td>
<td colspan="6">Q1:
(a) answer suggesting the respondent is unaware of theory-ladeness (answer #1, #2, or #4)
(b) answer suggesting the respondent is aware of theory-ladeness (answer #3)</td>
<td>- novice if {Q1: a}
- expert if {Q1: b}
- NA</td>
</tr>
<tr>
<td>VOS7
The models built by the scientists are distinct from the empirical reality</td>
<td colspan="3">Q2":
(a) answer suggesting clearly the respondent is taking the atomist description as the reality
(b) answer which does not suggest clearly the respondent is taking the atomist description as the reality, nor he is aware that the atomist description is a model (e.g., with no use of words like “model” or “representation”)
(c) answer suggesting the respondent is aware that the atomist description is a model (e.g., with the use of words like “model” or “representation”)</td>
<td colspan="3">Q9A:
(a) answer suggesting the respondent takes the heliocentric description as the reality (answer #3)
(b) answer suggesting the respondent is aware that the heliocentric description is a model (answer #1 or #2)</td>
<td>- novice if ({Q2": a} and {Q9A: a or NA}) or ({Q2": b or NA} and {Q9A: a})
- rather expert if {Q2": b or NA} and {Q9A: b}
- expert if {Q2": c} and {Q9A: b}
- depending on the context if ({Q2": c} and {Q9A: a}) or ({Q2": a} and {Q9:b})
- NA if {Q2": b} and {Q9A: NA}</td>
</tr>
</table>

VOS8 Errors may play a constructive role in the development of science	Q5 (multiple choice question): (a) “never” or “I don’t know” is checked (b) “sometimes,” “often,” or “always,” is checked	Q5' (“Explain why”): (a) answer which puts forward the negative role of errors (b) answer which claim the constructive role of errors in science but are not able to explain why (c) answer which claim the constructive role of errors in science and are able to explain why (d) not interpretable		- *novice* if ({Q5: a} and {Q5': a, d or NA}) or ({Q5: NA} and {Q5': a}) - *rather novice* if ({Q5: a} and {Q5': b or c}) or ({Q5: b} and {Q5': a, b or NA}) or ({Q5: NA} and {Q5': b}) - *rather expert* if {Q5: NA} and {Q5': c} - *expert* if {Q5: b} and {Q5': c} - *NI* if {Q5: b} and {Q5': d} - *NA*
VOS9 Interactions between scientists actively contribute to the construction and validation of scientific knowledge	Q6 (multiple choice question): (a) “not so important,” “not important,’ or “I don’t know” is checked (b) “very important,” or “important” is checked	Q6' (“Why?”): (a) no answer or answer with none of the two following ideas (b) answer with the idea that these interactions enable to communicate knowledge *or* that they enable cooperation or confrontation for the construction of knowledge (c) answer with both ideas	Q9B: (a) answer suggesting the respondent believes that the evolution of knowledge is due to isolated genius (answer #3 only) (b) otherwise (including NA)	- *novice* if {Q6: a} and {Q6': a or NA} (whatever the answer to Q9B) - *rather novice* if ({Q6: a} and {Q6': b or c}) or ({Q6: b} and {Q6': a or NA}) (whatever the answer to Q9B) or ({Q6: NA}, {Q6': NA} and {Q9B: a}) - *rather expert* if ({Q6: b}, {Q6': b} and {Q9B: b}) or ({Q6: NA}, {Q6': c} and {Q9B: b}) - *expert* if {Q6: b}, {Q6': c} and {Q9B: b} - *depending on the fact the question is contextualized or not* if {Q6': b or c} and {Q9B: a} (whatever the answer to Q6) - *NI* if {Q6: NA}, {Q6': NA} and {Q9B: b} - *NA*
VOS10 Realism *versus* instrumentalism with respect to the role of models	Q9A: (a) answer associated to naïve realism (answer #3) (b) answer associated to balanced realism (answer #1) (c) answer associated to instrumentalism (answer #2)			- *naïve realism* if {Q9A: a} - *balanced realism* if {Q9A: b} - *instrumentalism* if {Q9A: c} - *NA*
VOS11 Relativism or rejection of relativism concerning the influence of the socio-economic and cultural context on the construction of scientific knowledge	Q7: (a) answer associated to strong relativism (“yes” and “always” are checked) (b) answer associated to moderate relativism (“yes” and “sometimes” or “often” are checked) (c) answer associated to rejection of relativism (“no” is checked) (d) “I don’t know” or NA	Q8A': (a) answer associated to strong relativism (“yes” is checked at least for “on the interpretation of the outcomes” and/or “on the choice of the hypotheses”) (b) answer associated to moderate relativism (“yes” is checked only for “on the choice of the topics being investigated” and/or “on the allocation of human and financial resources”) (c) answer associated to rejection of relativism (“no” is checked for all item)		- *strong relativism* if answer (a) to both questions - *rather strong relativism* if ({Q7: b, d or NA} and {Q8A': a}) or ({Q7: a} and {Q8A': NA}) - *rather moderate relativism* if ({Q7: a or d} and {Q8A': b}) or ({Q7: b} and {Q8A': NA}) - *moderate relativism* if {Q7: b} and {Q8A': b} - *rejection of relativism* if ({Q7: c or d} and {Q8A': c}) or ({Q7: c} and {Q8A': NA}) - *NI* if (Q7: c} and {Q8A': a or b) - *NA*