Sci & Educ (2016) 25:795–822
DOI 10.1007/s11191-016-9846-2

ARTICLE

Discussion of the Controversy Concerning a Historical Event Among Pre-service Teachers

Contributions to Their Knowledge About Science, Their Argumentative Skills, and Reflections About Their Future Teaching Practices

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Published online: 2 August 2016

Abstract As part of a teacher training project, 16 future chemistry teachers participated in a dramatisation activity (a mock trial of the Fritz Haber case), in which they discussed a controversy concerning an event from the history of science: the awarding of the Nobel Prize in Chemistry to Fritz Haber in 1918. Preparations for the role-play activity, the dramatisation of the mock trial, and the subsequent discussions were video-recorded. We also collected the written material produced by the pre-service teachers and the reflective journals they produced during their involvement with the activity. This article discusses the contributions of such an experience to future teachers' knowledge on aspects related to both nature of science and argumentation, as well as to their views on their future actions related to authentic teaching *of* and *about* science. The results show that such contributions were meaningful.

1 Introduction

1.1 Science Teaching and Teachers' Education

Documents about science teaching published around the world over the past two decades (for instance, Millar and Osborne 1998; National Research Council 2012) have emphasised the importance of science education being more authentic, in other words, that the processes involved in teaching be closer to those which are part of science itself (Gilbert 2004). In a broad sense, this involves actively engaging students in their learning processes and, at the same time, changing their focus. This kind of change entails decreasing the emphasis on acquiring content knowledge and increasing the emphasis on learning about

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nature of scientific knowledge and scientific research, as well as promoting the development of skills related to higher-order thinking (for example, arguing, making comparisons, and solving complex, non-algorithmic problems) (Braga et al. 2012; Flick and Lederman 2006; Matthews 1998b; Zohar 2004). From this point, students can also understand the importance of acting as critical citizens, knowing the foundations of scientific knowledge, so that they can create their own justified opinions, and discuss situations where this knowledge is involved in some way. The main objective is to contribute to the development of a broader view of science and of the construction and use of scientific knowledge, which ultimately would result in science education becoming an important part of educating twenty-first century citizens.

Authentic science education can be promoted by involving students in investigative experiences, argumentative situations, and other contexts that may foster the development of knowledge about nature of science (NOS), as well as skills related to higher-order thinking. However, this depends on the involvement of teachers in planning and guiding educational processes consistent with this teaching perspective. In other words, it is essential that the teacher believe in the importance of promoting authentic science education, have the knowledge and the skills needed to promote it, and make all the necessary changes related to teaching it in their classrooms. Yet studies (Abd-El-Khalick and Lederman 2000a; Akerson et al. 2012; Hanuscin 2013, among others) have shown that this is not a simple task for teachers who generally do not learn about these teaching approaches in their training programmes nor experience them as students. In general, science teachers have not developed the knowledge and skills needed to teach from a perspective focused on students' *broad understanding about science*.

When we speak of changes in teaching perspective, we assume that adequate training is needed for teachers, that is, that they have to develop the knowledge and skills that will equip them to promote these changes, and not acquire a series of information about the proposed modifications, which most likely would only result in declarative knowledge about these changes. And considering further that understanding *about science* can be an important base for teachers to believe in the importance of promoting authentic science education, we conducted an extensive research project aimed at promoting and developing content knowledge and pedagogical content knowledge about NOS among pre-service teachers. In other words, we wanted to help pre-service teachers develop a broader view of science, as well as the skills and other expertise needed to teach about science.

In the last two decades, researchers from different countries have dedicated themselves to achieving this same goal. The approaches for each of various initiatives aimed at promoting the development of teacher knowledge about NOS were classified as *implicit* or *explicit* (Abd-El-Khalick and Lederman 2000a; Akerson et al. 2000). The implicit approach is characterised by the use of focused instruction in skills related to science processes and/or scientific investigation activities such that teachers understand aspects of NOS through these experiences (even if they have not had opportunities to think explicitly about these aspects). Meanwhile, the explicit approach assumes that the understanding of science is one of the expected outcomes of teaching and, in this sense, such an understanding must be clearly promoted. Consequently, studies related to this perspective (for instance, Akerson et al. 2000; Allchin 2013; Demirdögen et al. 2016; Irzik and Nola 2014; Rudge and Howe 2009; Vesterinen and Aksela 2013) use elements of history and philosophy of science and/or specific instructions related to various aspects of NOS and also emphasise discussion and critical reflection by the subjects on these aspects in order to promote the development of a broader view of science, thus contributing to the subjects' scientific literacy.

Based on an intense reading of the literature in this area and reflecting on our previous experiences in teacher education, we agree with Abd-El-Khalick and Lederman (2000a) when they claim that explicit approaches are more effective in promoting understanding of NOS among teachers, mainly as a result of the subjects discussing and reflecting on the topic. In addition, some advocates of the explicit approach maintain that aspects of NOS should be addressed in an integrated manner, and suggest the use of (historical or contemporary) case studies and scientific research as possibilities (Allchin 2013; Khishfe 2014; McComas 2008) for including NOS in science teaching.

1.2 Nature of Science and Science Education

Currently there does not seem to be disagreement about the relevance of inserting discussions about nature of science into science education. Several authors have advocated the need for reflection on *what* and *how* to teach about NOS (Allchin et al. 2014; Irzik and Nola 2011; Matthews 1998a).

One of the most widespread proposals for teaching NOS is based on a list of seven principles proposed by Lederman et al. (discussed, for instance, in Abd-El-Khalick et al. 1998; Lederman 2006; Lederman et al. 2002): "scientific knowledge is tentative; empirically-based; subjective; necessarily involves human inference, imagination, and creativity; is socially and culturally embedded; observations are different from inferences; and the functions of, and relationships between scientific theories and laws" (Lederman 2006, p. 304).

The idea of inserting NOS into education from lists of principles has been criticised in recent years. One criticism addresses the fact that the principles are based on the epistemology of science, in other words, on the norms and values of the production of scientific knowledge. For Allchin (2011, 2013) and van Dijk (2011, 2013), the separation between scientific practices (for example, those involved in the development, testing, definition of validity and reliability, and communication of scientific knowledge) and nature of science is artificial, since scientific practices constitute science.

Irzik and Nola (2011, 2014) and Wong and Hodson (2010) criticise the idea that the list would characterise science in a homogeneous manner. For these authors, the list of NOS principles does not consider the existence of distinct sciences (biology, physics, geology, chemistry, etc.), which have specific features related to most of the principles (for example, in relation to the empirical nature of scientific knowledge). In this sense, they argue that NOS cannot be fixed and timeless. Along similar lines, Allchin (2011) states that the list of NOS principles does not capture the contextual aspects of science, and ends up reinforcing a number of stereotypes.

Allchin (2011) also criticises the way the principles on the list are presented in science education since; according to him, there is no evidence that declarative knowledge about NOS can support its application in the analysis of cases involving components of science in everyday situations. For example, in order to be able to evaluate the results of research on global warming (whether environmental damage is the result of human action), it is necessary to consider NOS aspects, such as the reputation of the scientists involved, the sources of research funding and associated interests and biases, and the role of evidence in producing consistent arguments. According to Allchin, just knowing, for example, that knowledge is subjective (as opposed to objective) does not guarantee that the subject knows how to make judgements rationally when this kind of knowledge is needed in a practical situation. He also emphasises that several aspects are missing from the list, such as the roles of credibility, financing, motivation, peer review, cognitive biases, fraud, and validation of new methods.

Such criticism has raised many discussions among researchers on how to insert NOS into science teaching to foster the development of broader knowledge of science. Similarly, some studies recommend the importance of introducing discussions about scientific methods into school curriculum (for instance, Osborne et al. 2003), which is a position contrary to the separation between scientific processes and NOS present in the perspective proposed by Lederman et al.

As a proposal for teaching NOS, van Dijk (2011, 2013) defends the gathering of case studies involving socio-scientific issues that may reveal important aspects of NOS for scientific communication. The various case studies form an empirical basis for developing an appropriate structure that would represent the differences and similarities characterising the individualities of the sciences. Allchin (2013) presents a collection of historical cases with identification of NOS aspects that emerge from them and pedagogical proposals for their use by teachers. According to him, the cases of historical simulations are open exercises for exploring NOS by proposing particular problems in specific historical contexts.

During this study, in our analysis of science perspectives presented by teachers, we did not use any list of NOS principles. On the contrary, we considered the broader views that have been recently defended (for example, those presented in Allchin 2012a, 2013; Erduran and Dagher 2014; Erduran and Mugaloglu 2013; Irzik and Nola 2014; Justi and Erduran 2015; Matthews 2012). These perspectives consider various aspects in characterising science (aspects such as those related to the philosophy, history, sociology, psychology, and anthropology of science, as well as cognitive and economic aspects related to the production, communication, and use of scientific knowledge) and recognise the existence of specificities among the different sciences. Although many points concerning the characterisation of NOS are still under discussion (Abd-El-Khalick 2012; Allchin 2011, 2012b; Deng et al. 2011; Duschl and Grandy 2013; Hodson 2014; Kampourakis 2016; Matthews 2012; Schizas et al. 2016; Schwartz et al. 2012, among many others), we agree that such broader views are consistent with the aims of our project.

1.3 Argumentation and History of Science

In general, argumentation can be understood as a socially situated activity in which individuals produce and justify claims based on empirical or theoretical evidence (Kuhn 1991; Toulmin 1958). There seems to be a consensus among the community of researchers related to the development of argumentation in science classrooms to encourage: (i) the learning of scientific concepts, as students gain more clarity about certain concepts, models, or theories when they understand why these concepts, models, or theories are more coherent or comprehensive than others (Berland and McNeill 2010; Jiménez-Aleixandre and Erduran 2008; Osborne et al. 2004, 2013); (ii) the understanding of how science takes place, because students come to understand the importance of evidence and justifications in producing and defending scientific explanations and relate persuasion with well-founded arguments (Berland and Reiser 2009; Sandoval and Willwood 2008); and (iii) the understanding of science itself, since argumentation is a practice which is present in the development, validation, and dissemination of scientific knowledge (Ryu and Sandoval 2012). In short, science education ceases to be “a rhetoric of conclusions” when there is room for argumentation (Duschl and Osborne 2002).

In light of the benefits of argumentation in the processes of science teaching and learning, it is necessary to incorporate into teacher education discussions about the knowledge inherent to argumentation, to foster teacher participation in activities aimed at promoting argumentation in their own practice, and to encourage them to produce teaching materials and teaching strategies that promote argumentation in science classrooms (Simon et al. 2006; Zembal-Saul et al. 2002). However, there are few studies that focus on the investigation of argumentation in the context of teacher education (such as those mentioned above) compared with those related to argumentation in primary and secondary education (for example, Berland and McNeill 2010; Chin and Osborne 2010; Christenson et al. 2014; Evagorou et al. 2012; Jiménez-Aleixandre et al. 2000; Kelly et al. 1998; Mendonça and Justi 2013; Passmore and Svoboda 2012; Sampson et al. 2011; Zohar and Nemet 2002).

Some types of activities that have the potential to promote argumentation in the classroom, such as the use of investigative activities, discussion of historical episodes, and debate around socio-scientific issues are discussed in the literature (Cavagnetto 2010; Osborne 2007; Zemplén 2011). The types of speech (conventional debate or role-playing) are also indicated, along with cases or problems as possible strategies for developing argumentation and decision-making among students (Simonneaux 2001, 2008).

With regard to role-playing, Simonneaux (2008) states that this strategy allows other points of view to be understood, since subjects need to place themselves in a situation they do not believe in or would not defend in a conventional debate. In this sense, constructing activities based on role-playing to improve the argumentative capacities of teachers and also to develop their pedagogical content knowledge appears to be an interesting option, especially considering that one of the barriers to implementing argumentation in science classrooms is the fact that few examples of teaching strategies are presented to pre-service teachers (Zembal-Saul et al. 2002). Two types of role-playing activities, mock trials (Vieira et al. 2015) and dramatisation involving historical episodes (Archila 2015), have not been widely explored as resources for promoting argumentation in primary and secondary education, as well as teacher education.

Historical controversies, that is, past debates concerning conflicting scientific matters, have been used to encourage explicit discussion of elements of NOS (Allchin 2014; McComas 2008). This has occurred both in the context of teacher training (Abd-El-Khalick and Lederman 2000b; Niaz 2009), as well as in primary and secondary education (Braga et al. 2012) in order to promote a better understanding of the scientific knowledge involved and to broaden the knowledge of teachers and students about science. Historical controversies can also be used to generate argumentative situations (Zemplén 2011), since the subjects must argue in favour of certain ideas and refute others based on evidence and relevant knowledge in the light of both the historical facts and the context of the period studied. In this way, historical controversies can play an important role in argumentation by providing evidence that can be used against and in favour of decisions (Archila 2015). Argumentative activities involving historical controversies can be conducted in order to promote the understanding that different viewpoints can coexist and that, in a given context, one may be considered more appropriate than another. These activities are not easy to be conducted in teaching since they require a great deal of preparation on behalf of the students, especially those defending ideas that are not supported by the modern scientific community (Allchin 2013).

Despite the potential for using historical episodes as a strategy for promoting argumentation, this subject still needs to be further investigated (Böttcher and Meisert 2011; Khishfe 2012; Zemplén 2011). Recently, Archila (2015) proposed a sequence of teaching activities based on the historical controversy over the discovery of oxygen to promote students' understanding of aspects related to the role of experiments and communication in science, and to promote student argumentation related to deciding which scientist or scientists involved in the controversy were actually responsible for the 'discovery' of oxygen. According to Archila, the ambiguity involved in the response to this historical controversy can help engage students in argumentation. In analysing the data, Archila (2015) found a very low frequency of evidence use related to scientific communication, which was seen as a measure of the lesser relevance given to this evidence by the students and/or their greater tendency to assess evidence related to experimentation compared with those related to communication. Archila emphasised that this result is a reflection of the relationship between students' arguments and their views of science (Khishfe 2012; Zemplén 2011). In the proposal investigated by Archila (2015), the students did not experience explicit teaching of argumentation and, in particular, were not prepared to evaluate evidence and relate them to the aspects of NOS that were studied.

The literature also discusses the relevance of teaching NOS and argumentation in an integrated and explicit manner (Khishfe 2012; Sadler et al. 2004; Zeidler et al. 2002), since the explicit approach to both could help students develop a more appropriate view of science. However, few studies have investigated this relationship with this objective (Osborne et al. 2013; Sandoval and Willwood 2008).

2 Research Questions

Considering the issues that have been discussed so far, we developed an extensive research project based on an explicit approach for teaching NOS to pre-service teachers completing their teaching degree in the area of chemistry. One of the stages of the project relates to the history of science and aims at providing conditions for these pre-service teachers to learn about NOS by analysing historical episodes and engaging in argumentative situations in order to discuss such episodes or aspects related to them. This article is part of this broader project and addresses the following research questions:

- Which aspects of nature of science do pre-service teachers identify as important when they participate in discussions about a controversy related to the history of science?
- What are the characteristics of the arguments presented by pre-service teachers when they discuss a controversy related to the history of science?
- How do pre-service teachers assess the contribution of discussing a controversy related to the history of science to their future work as teachers?

3 Method

3.1 Sample

The participants of this study included 16 students from a teacher education course in chemistry at a public university in South-Eastern Brazil. They were involved in a project at that university designed to stimulate teaching, with the following key objectives: to promote integration between the university and primary and secondary schools; to improve the quality of initial teacher training; to place pre-service teachers into public school life through their preparation and participation in innovative methodological experiences that seek solutions to problems often encountered in the teaching and learning processes; and to promote connection between theory and practice necessary for teacher education, in turn improving the quality of initial teacher training programmes.

The pre-service teachers were selected to participate in the project based on their interest in improving their training and in actually working as primary or secondary school teachers upon completion of their degree. Such an interest was evaluated from both the fact that they had decided to apply for participating in the project (which meant to dedicate 15–20 h per week to such an extra activity) and from their answers when interviewed about teaching, schools, and current dilemmas faced by teachers in our country. The teacher education programme at the university in question requires students to take courses and participate in other academic activities for eight semesters. The 16 students who participated in the project were between their 2nd and 6th semester when the activities related to this project were carried out (two of the 16 were in the 2nd semester, eight were in the 4th, and six were in the 6th semester of the programme). Additionally, none of the 16 had any previous formal teaching experience. Therefore, their knowledge related to chemistry and chemistry education varied widely. Consequently, during all of the activities undertaken in this project, the groups of students were formed with the aim to maintain the heterogeneity of the sample; in other words, they contained students from various programme semesters.

The pre-service teachers were informed about the aims of the project, as well as about the ethical procedures that would be taken (mainly concerning the use of data for research purposes only, the non-identification of the individuals or the university in all publications of the study, the possibility they would have to abandon the study whenever they want, etc.). After providing all explanations and discussing their doubts, they signed a term of agreement that had been previously approved by the Ethical Committee of one of our universities.

All of the activities of this project were planned by our research team (consisting of researchers, master's and doctoral students in the field of science education, as well as high school chemistry teachers). The discussions with the pre-service teachers were coordinated by the authors of this article.

3.2 Context of the Study

At the beginning of the project, the pre-service teachers completed a questionnaire about their views on science. It is out of the scope of this article to discuss such a questionnaire (that was previously validated and had its reliability confirmed by some experts in the area) because our focus here is not on such detailed methodological issues of the study. But it is important to say that the pre-service teachers' answers showed naïve views, mainly emphasising, for instance, that science results only from the use of empirical methods of data collection and analysis. Such naïve views permeated what they said in the initial discussions about the meaning and importance of promoting authentic science education. After such discussions, the pre-service teachers participated in two activities involving the history of science that aimed at changing and broadening their views of science.

The main objective of the first of those activities was to familiarise the pre-service teachers with historical cases so that they could begin to think about some features of the process of producing and developing scientific knowledge. To this end, they were divided into four groups with each group being given a set of texts on a particular topic. The sets were focused on the history of the development of given scientific ideas, on the work of some scientists, or on simple historical controversies. They were organised in order to provide some information about the processes, agents, and products involved in science.

Our main aim was to create a context involving problematic issues around science that could foster further discussions. For example, one of the groups received texts about Lavoisier and his book *Elements of Chemistry*, all of which aimed to encourage the development of a more realistic view of this scientist, his work, and his role in the history of chemistry. Another group received texts on the work of four scientists (K. Mohr, F. Joliot, L. Pasteur, and R. Diesel) that aimed to foster a broader view about the different personalities of scientists and the understanding that a scientist's work can be influenced by social, economic, and political factors (as the simultaneous analysis of the work of those scientist could show). All the texts were in Portuguese and from reliable secondary sources (books on history of science). In all cases, the pre-service teachers were supposed to "tell the story" present in the set of texts in a creative manner, that is, not through a formal seminar.

The final discussion of this activity mainly involved questioning the pre-service teachers about what they had perceived and learned about the development of scientific knowledge when they studied the texts and prepared to present the story to their classmates. This discussion was very important to hone the pre-service teachers' critical ability, a skill that would be key for performing the next activity. The content analysis of the videos of that discussion showed that although almost all the pre-service teachers changed their initial views on science, their ideas already presented many gaps. For instance, although most of them asserted that 'scientists are not geniuses', 'scientists face difficulties in their work', 'scientists may have distinct ideas about a given matter', 'scientists may collaborate with each other', 'science needs money to be developed', they were not able to justify and/or deeply discuss most of their affirmatives. After that activity, few pre-service teachers showed a more comprehensive and in-depth view on science, that is, only few of them were able, for instance, to critically analyse the role of funding or to properly relate external factors and personal characteristics of given scientists to explain the historical development of a specific idea.

The second activity, which is the main focus of this article, involved a controversy related to a historical fact. A controversy of this type is different from a historical controversy. As previously mentioned, a historical controversy is a situation in which two or more scientists develop different and conflicting knowledge on the same topic (for example, different interpretations of the same experiment). A simple example was the debate between Thomson and Rutherford on their explanations for the origin of the large angle deflection of alpha particles (Niaz 2009). Historical controversies have been used in teacher education (Abd-El-Khalick and Lederman 2000b; Niaz 2009) and in primary and secondary schools in order to expand the knowledge of teachers and students about science, among other objectives. In our project, we decided to use a controversy related to a historical event, that is, a debate concerning a historical event, but not focused on conflicting knowledge. The controversy involved an event that occurred at the beginning of the twentieth century: the awarding of the 1918 Nobel Prize in Chemistry to Fritz Haber. In our view, both types of controversy can promote reflections on science. Nevertheless, we chose to use a controversy over a historical event (about which the pre-service teachers had no prior information) because we believed that this would promote a more "neutral" involvement in the discussion. In other words, we believed that, in previously resolved controversies involving scientific knowledge, the pre-service teachers could more safely defend the position related to the consensus in the scientific community, that is, to what was eventually accepted as scientific knowledge. Consequently, the controversy we presented them with did not involve judging the validity of a piece of scientific knowledge, but instead analysing the event in the light of the context in which it took place.

This particular case was chosen for two main reasons. First, it involved the possibility of exploring various aspects of NOS that have the potential to demystify a range of stereotypes about science and scientists. Second, the case involved a controversial historical figure, as Fritz Haber was involved in World War I investigations on gases used in the battlefield, which could be a very provocative topic for basing an argumentative situation.

In order to ensure their engagement with participating in the activity, the pre-service teachers were given some texts concerning the history of Fritz Haber, the development of the process to produce ammonia, and the historical scenario in which this development took place. These texts consisted of primary sources (for example, the speech Haber gave upon receiving the Nobel Prize) (Haber 1920) and secondary sources (articles telling the story of the synthesis of ammonia, examining some aspect of this story or related to the character of Haber, or contextualising the economic and political aspects of the late nineteenth and early twentieth centuries (for instance, Huxtable 2002; Wisniak 2002). The pre-service teachers were told that these were basic texts that all of them should read, and that they should look for other sources of information.

Among several other information, from those texts, the pre-service teachers would know that Haber received the 1918 Nobel Prize in Chemistry for synthesising ammonia from its elements, nitrogen and hydrogen. The Nobel committee considered that as the most important chemical discovery or improvement because the artificial production of ammonia and nitric acid had become essential in order to produce fertilizers, since there was no natural source available at that time (World War I). Since the beginning of the twentieth century, other scientists (mainly Le Chatelier and Bosch) had proposed methods to synthesise ammonia from its elements, but none of them could be used on an industrial scale. Additionally, the synthesis of ammonia from nitrogen and hydrogen was very difficult because the three gases take part in a chemical equilibrium in which the production of ammonia is an exothermic reaction. According to the law of chemical equilibrium, this means that the production of ammonia is favoured by high pressures, but not by high temperatures. Haber was able to not only determine the proper values of pressure and temperature, but also to identify a good catalyst for the reaction (which also contributed to reduce the pressure applied into the gaseous system), and to propose that the gases should be given a greater flow rate during the reaction.

The four elements had been previously predicted independently by W. Ostwald and H.W. Nernst. Ostwald had applied for a patent of the process (the application was taken out after a report by K. Bosch (requested by BASF, the company that funded Haber's work) informed that, from Ostwald's method, a small quantity of ammonia was produced from a different reaction. Even before that, Le Chatelier obtained a patent for producing ammonia from hydrogen and nitrogen at higher pressures, but had to stop the high-pressure experiments due to an accident that killed one of his assistants. Haber, working with one of his assistants, planned, built, tested, and modified an apparatus where the reaction could occur under the necessary thermodynamic conditions. On the other hand, Haber also worked on the production of poisonous gases used as weapons at the trenches, and advocated massive gas attacks. Haber's activities related to World War I resulted in a series of criticisms from the international scientific community. The relationship between Haber's work and the war, as well as the doubts about the extent to which his assistants had contributed to the success of his work, have resulted in a disagreement about the decision to award him the Nobel prize in the first round of meetings. In a following meeting, this decision was reversed by the same committee.[1]

[1] This is a very brief summary of some of the events concerning Haber's academic life. It was introduced to help the reader to understand some of our data and discussions. For more details, see, for instance, Huxtable (2002) and Wisniak (2002).

The controversy was presented to them in the form of a question: *Did Fritz Haber deserve to win the Nobel Prize in Chemistry for synthesising ammonia from its elements?* The pre-service teachers were informed that a mock trial exercise would take place during a subsequent meeting to discuss this question. To this end, they were divided into two groups: one maintaining that Haber deserved to win the prize (the Defence), and the other defending the opposite position (the Prosecution). As in all other activities undertaken in our project, the groups were divided maintaining the heterogeneity of the sample, that is, the groups were composed by equal number of students from different academic semesters. One important condition was established which had to be observed in the mock trial: all arguments used had to be placed into the context preceding the date of the ceremony award (June 2, 1920).[2] This meant that the participants could not use arguments based on facts that occurred, or knowledge that was produced, after this date.

The pre-service teachers had 3 weeks to prepare their arguments. During this time, two meetings (with a total duration of 6 h) with the authors of this study took place, in which the pre-service teachers were able to clarify any doubts they had on the subject and discuss their interpretations of the texts in order to produce the arguments they would use. The two groups also met separately at other times to complement their discussions. During these meetings, there was no explicit teaching of argumentation. Four of the pre-service teachers (divided between the two groups) had already studied the importance of using evidence to justify their views in a regular course which was part of the teacher training programme.

In terms of the dynamics of the mock trial exercise, the pre-service teachers were informed about the details of the session, in particular (i) the time each group would have to present their opening arguments, the reply, and the rejoinder, (ii) the fact that all the arguments used needed to be delivered to the judge in written form at the end of the trial, and (iii) the criteria that would be used in preparing the verdict: the quality of the arguments and rebuttals expressed in all phases of the trial. Finally, we recommended that the mock trial should not involve merely reading the arguments, but it should instead involve dramatization. This would entail setting a scene they could enact and using costumes they deemed appropriate. This was done in order to increase the pre-service teachers' motivation to participate in the activity.

The mock trial activity was staged with one spokesperson and two assistant attorneys for each group. In addition, there was a judge (the second author of this article) who coordinated the session. The segments of the trial, with special emphasis on the participation of the Prosecution and Defence groups, are summarised in Table 1. The whole duration of the section was 165 min. While the spokesperson for each group spoke, the members of the opposing group took notes on the content of the presented arguments to support their own rebuttals and/or new arguments that would be subsequently presented.

The verdict of the trial was made by the authors of this study after analysing the arguments submitted by the groups, and was only communicated and discussed with the pre-service teachers in the week following the trial. When the verdict was presented and discussed, all the aspects of science that were used in the arguments from the Prosecution and Defence (or those that could have been used based on the previous discussions in which the pre-service teachers had participated) were discussed with them. In this discussion, as in all the others, we did not present any new features of science to the future teachers; in other words, all the aspects we discussed emerged from the ideas they

[2] The ceremony took place in 1920 because in 1918 "the Nobel Committee for Chemistry decided that none of the year's nominations met the criteria as outlined in the will of Alfred Nobel". Therefore, the Nobel Prize in Chemistry 1918 was announced on November 13, 1919 (Nobelprize.org Nobel Media AB 2014).

Table 1 Time duration of the mock trial

Order	Segment	Time duration (min)
1	Presentation of the Prosecution's initial arguments	30
2	Presentation of the Defence's initial arguments	30
3	Interval for the groups to prepare their replies	40
4	Presentation of the Prosecution's reply	15
5	Presentation of the Defence's reply	15
6	Interval for the groups to prepare their rejoinders	15
7	Presentation of the Prosecution's rejoinder	10
8	Presentation of the Defence's rejoinder	10

expressed after analysing the historical events or parts of the texts in which they had not identified some aspects of NOS. Additionally, we detailed and explained the criteria used in the analysis of the arguments. Our goal was for the participants to not only understand the verdict of the trial, but also learn about argumentation and NOS.

3.3 Data Collection

Data were obtained through video recordings of the meetings in which the texts were discussed, the arguments were produced, the trial was held, and the verdict was discussed. We also collected the written material (the list of arguments to be used in each step and other observations about the process) produced by the pre-service teachers.

In addition, throughout the project, the pre-service teachers kept weekly reflective journals in which they were to register their impressions of each meeting (of the whole group or their working group), their questions, their reflections on what they were learning, and how they perceived the relationship between the activities carried out in each session and their future teaching practice. In order to produce this article, we used the reflective journals that were written during trial preparation, immediately after it was completed, and after the discussion of the verdict.

In this sense, our work differs from other projects published to date which are related to developing teacher knowledge about nature of science (Akerson et al. 2012; Akerson and Hanuscin 2007; Demirdögen et al. 2016; McDonald 2010; Sorensen et al. 2012, dentre outros). According to a broad review of the methodologies used in studies that assess the ideas teachers have about NOS (Guerra-Ramos 2012), most of these studies use questionnaires and interviews as data collection instruments. To a greater or lesser extent in all of these studies, all the ideas expressed by the teachers were directed by pre-formulated questions. In our decision to analyse the pre-service teachers' reflective journals, we took into consideration that, since these were in a free-text format, they would contain the thoughts and questions that were really relevant to them. Given that we also opted to analyse the statements and dialogues established during the mock trial sessions and the verdict (in which they had the opportunity to speak about all the aspects discussed), we believe that the data we obtained reflected the complex network of ideas held about NOS by the pre-service teachers at that time.

3.4 Data Analysis

To provide responses to our research questions, we analysed the videos and written material (records of the arguments and other comments, as well as the parts of the reflective journals mentioned in the previous item) in order to identify:

(i) all the times when the pre-service teachers showed some knowledge about science deriving from the discussion of the controversy to be addressed in the mock trial. In doing so, we attempted to understand the meaning of the ideas expressed by the pre-service teachers, instead of judging them in terms of pre-established categories or categorising them in terms of different philosophical views (whether appropriate or not). Considering the broad view of NOS that guides our work (Allchin 2013; Allchin et al. 2014; Erduran and Dagher 2014; Justi and Erduran 2015; Matthews 2012; Nielsen 2013), we identified all the times when the pre-service teachers mentioned aspects related to the philosophy, history, sociology, psychology, and anthropology of science, as well as cognitive and economic aspects related to the production, use, and communication of scientific knowledge;

(ii) all the statements that the pre-service teachers classified as arguments. Some of them were actually arguments according to the literature (Jiménez-Aleixandre 2010; Toulmin 1958), that is, they were justified claims. However, some of them were not arguments (for instance, only claims), while some were a set of arguments, all of them closely related to each other. Therefore, we named all of 'pre-service teachers' arguments', PSTA. When analysing the PSTA, we sought to identify certain elements as the main constituents of the argument (see Jiménez-Aleixandre 2010; Toulmin 1958). To do so, we identified: the *claim*, which is the idea that the group intended to defend; the *evidence*, which is the information, data, or statements that could be found in the texts and would support the claim; and the *justification,* which is a statement that indicates why one piece of evidence can be accepted to support an explanation or an inference that supports the claim. Next, the evidence was classified as *strong* or *weak* according to whether it was coherently related to the claim and whether it was based on the elements present in the historical texts. The justification was classified as *strong* or *weak* as a function of its ability to establish a coherent relationship between the evidence and the claim or to be a relevant type of inference.

(iii) the *basis of argumentation*, which is the type of strategy or reasoning used in constructing the argument. Each of the authors of this article, working independently, identified such bases from content analysis of the data itself. Then, our individual analyses were discussed with the other members of our research group until we reached an agreement. As a result, the basis of argumentation used by the pre-service teachers were grouped into ten items: emotional appeal, the scientist's character (positive or negative), scientific aspect, criteria for awarding the Nobel Prize, negative consequences of the production of knowledge, negative consequences of the use of knowledge produced, historical aspects, legal aspects, aspects related to NOS, and technological aspects. Some PSTA contained more than one basis for argumentation.

In order to facilitate understanding on the part of the reader, we show some examples of classification for the PSTA used in the trial. In these examples, as in all other discussed in this article, the claims are presented in bold, the evidence is underlined, and the justifications are presented in italics. In some cases, the justification is not identified because the pre-service teachers used only evidence or relationships between evidence and the claim (implicit in the text) to justify their claims.

> **Haber was a great scientist, one of the best physical chemists known to the present day**, and he learned almost everything on his own. Despite all the difficulties he encountered in the new city, Haber overcame all of them, and therefore stood out because of his great qualities, which included: an enormous capacity for work, tenacity, exhaustive rigour, broad theoretical knowledge and associative capacity. He also taught various subjects such as chemistry of gases, dyes, and electrochemistry. [Defence, scientist's character (positive), strong evidence]

> **The defendantproved himself to be ruthless and inhuman** because *what he synthesised left millions dead during World War I.* [Prosecution, scientist's character (negative) & negative consequences of the knowledge produced, weak justification]

> **Other scientists had already synthesised ammonia, Haber was not the first**… The defendant was nominated for the Nobel Prize for synthesising ammonia from nitrogen, but le Chatelier had previously concluded from his own principle that the process of synthesising ammonia was possible using high pressures and temperatures when a catalyst was present. However, what made it impossible for le Chatelier to produce ammonia was the lack of equipment and resources, such as reactors that could withstand high pressures and temperatures. Le Chatelier had even already patented these studies using a pseudonym. [Prosecution, scientific and historical aspects, strong evidence]

> **Science cannot be characterised as good or bad**. *These conflicts about the use of scientific knowledge are separate from the knowledge itself.* [Defence, aspect related to nature of science, strong justification];

(iv) whether the PSTA expressed in the reply and the rejoinder were meant to actually refute those proposed by the opposing side;

(v) the excerpts from the pre-service teachers' reflective journals, in which they expressed specific reflections on their future teaching performance based on their experiences during the activity analysed herein.

After defining the criteria for analysis and conducting a joint initial analysis, eight of the other members of our research team also identified the aspects of NOS and analysed every PSTA. In this way, the result of the analyses originated from the consensus which was attained after triangulation between our original analysis and that of each group member. Next, we organised the material that resulted from these analyses into lists and tables to facilitate discussion of important aspects with the pre-service teachers. Some of them are presented in the following section in order to support the discussion of our research questions.

4 Results and Discussion

In order to facilitate understanding of the discussion of the results, we introduce the results based on each of the research questions that guided this study.

4.1 RQ1: Which Aspects of Nature of Science Do Pre-service Teachers Identify as Important When They Participate in the Discussion of a Controversy Related to the History of Science?

Several aspects of NOS were specified during the discussions of the texts in both groups, while the trial was taking place, during the verdict, and after these events (in the reflective journals). The key aspects, that is, those that support discussions between students (rather than being only mentioned) are summarised in Table 2.

The set of these aspects comprises a broad view of the production and use of scientific knowledge which, though incomplete (in terms of supporting the analysis of every situation involving science) was considered satisfactory at the time, since it encompassed all the aspects that could emerge from the controversy that was discussed. The fact that these aspects emerged from the discussion of the proposed controversy is clearly evident when we analyse the reflective journals of some of the participants. For example, as one of the pre-service teachers wrote in her reflective journals while preparing for the trial:

> Science is entirely connected to social, political, philosophical, religious, economic, etc., factors. In this sense, the story of Fritz Haber illustrates these aspects very well. [Pre-service teacher 1 from the Defence group; aspect 10 from Table 2]

After the trial, these and other aspects were clearly specified, as evidenced in the following quotes (selected from among many others):

> When discussing the study conducted by Haber over 10 years, it was possible to see the non-linear and discontinuous character of science. It is commonly held that the work of a scientist comes down to proposing a question, developing hypotheses, and conducting experiments that will surprisingly support these hypotheses, making them become "truths". In examining the work that Haber and scientists before him did in trying to synthesise ammonia, we can perceive that science is filled with failed attempts, results that do not always meet expectations, and various other obstacles. [Pre-service teacher 1 from the Defence group; aspects 5, and 6 from Table 2]

> Considering the fact that science is a human production, it is important to stress that feelings, desires, and needs are aspects that heavily impact the production of knowledge. In the Haber's case, it is very clear that his nationalist sentiments, as well as his desire to see his nation developed and independent, are factors that pushed him towards devoting his studies to synthesising ammonia. His desire to see his country victorious in the war led Haber to dedicate himself to studying the production of gases, which would be later used by the German army as chemical weapons. Maybe these are the factors that most help us to see the human character of science. [Pre-service teacher 3 from the Defence group; aspects 1, and 10 from Table 2]

> Another reflection conceived from these discussions is that often knowledge is produced from the needs of society. Haber did not direct his studies towards synthesising ammonia, producing gases, producing catalysts, etc. merely because of an affinity with this content. On the contrary, there was an entire social, political, and economic context that led Haber to choose these subjects as his object of study. [Pre-service teacher 6 from the Prosecution group; aspect 10 from Table 2]

> The story of Fritz Haber is also a clear example of how scientists are not solitary and lonely people. Haber enlisted the help of other scientists like Carl Bosch to advance his studies, which contributed towards making large-scale ammonia production viable. Furthermore, Haber had financial support from BASF to conduct his research. This leads us to think that the work of Haber was not limited only to using his scientific and technical knowledge. Before this, he had to convince others that his work was promising and that they should support him. [Pre-service teacher 8 from the Defence group; aspects 9, 10, and 12 from Table 2]

> During the activities we participated in, my view of what science is was expanded, and maybe my personal experience is the best example that I have that studying the history of science helps to make it more human. Furthermore, I could see that I had a very idealistic and minimalistic perspective of science compared with how it really is. Science, with all its variables, factors, and complexity, goes

Table 2 Key aspects about science as explained by the pre-service teachers

1. Science is a human production, conducted by normal people (and not by geniuses)
2. Science cannot be labelled morally good or bad; in other words, scientific knowledge itself does not have this character, although it can be used for "good" or for "bad"
3. Scientific knowledge is constructed from evidence of various natures
4. Knowledge needs to be published in order to be discussed and accepted as scientific
5. Scientific knowledge is provisory, and therefore is not absolute truth
6. The production of knowledge is a gradual and non-linear process in which unforeseen events and "errors" take place
7. The production of scientific knowledge requires creativity and motivation on the part of the scientists
8. Production of knowledge requires persistence, an investigative spirit, and significant amounts of study on the part of the scientists
9. Production of knowledge occurs collaboratively between various scientists (at the same time and at different times)
10. Both the production and use of scientific knowledge are influenced by the historical context (political, economic, social, cultural, and religious)
11. Various psychological characteristics and traits of the scientists influence the production and dissemination of scientific knowledge
12. Funding is necessary and important to conduct research

> far beyond what I thought. [Pre-service teacher 5 from the Prosecution group; general view on the experience]

The level of detail in many of these quotations indicates that involving the pre-service teachers in the intense and fierce discussion of the controversy proposed herein decisively contributed to their actual understanding of the aspects of NOS presented in Table 2. In our view, the level of understanding of these aspects exhibited by the pre-service teachers at that time would be able to support the analysis of other situations (related to historical events or contemporary social and scientific situations), as well as future teaching work that would incorporate this broad view of science.

4.2 RQ2: What are the Characteristics of the Arguments Presented by the Pre-service Teachers When They Discuss a Controversy Related to the History of Science?

Keeping in mind the more dynamic nature of the reply and rejoinder phases, we presented the results of these separately from the presentation of the opening arguments.

Part A: Presentation of opening arguments

In the opening statement by the Prosecution group, five themes permeated their PSTA.

1. *Haber was a nationalist, militarist, inhuman, egocentric* (*in sum, a monster of a human being*). Fifteen PSTA related to this theme were produced, founded on the following: the negative character of the scientist (10), the emotional appeal (6), the negative consequences of the knowledge produced (1), the negative consequence of the use of the knowledge produced (3), the historical aspects (3), and the scientific aspects (3). Eleven of these PSTA were supported only by evidence, seven considered as strong and four considered as weak, while three PSTA were only justified, with one of these

justifications considered as strong and the other two considered as weak. Only one PSTA simultaneously exhibited evidence and justification:

> Witness reports prove that the defendant only converted to Christianity to gain access to public office, *since Jews did not have many privileges with relation to these positions*, **further demonstrating his egocentricity**. [Prosecution, scientist's negative character & emotional appeal].

In this case, the evidence was classified as weak and the justification as strong, because it did neither specify who the witnesses were nor the context of their report in order to lend strength to the claim. Furthermore, considering the justification, the evidence is weak.

2. *Other scientists had already synthesised ammonia, so Haber was not the first to do so.* This PSTA was based on a scientific aspect and featured a strong piece of evidence;
3. *Haber denied knowledge of reports of previous research in which ammonia was synthesised.* A PSTA based on the historical aspect was produced and was composed only of a claim;
4. *Haber did not work alone.* Two PSTAs were produced, both based on scientific aspects. One had strong evidence and the other featured strong justification;
5. *Giving Haber the award goes against the criteria defined by Nobel for the winners of the prize.* Two PSTAs were produced, one being based on the criteria for awarding the Nobel Prize and the other on a historical aspect. One presented a weak piece of evidence and the other had a weak justification.

From these data, we can say that the Prosecution group focused their discussion on the first topic and presented a variety of evidence to support their assertion. However, most of this evidence was presented with an emotional appeal in order to denigrate the character of the scientist. The group did not focus on arguments based on scientific knowledge and on historical aspects, which are necessary in argumentation. For example, the Prosecution could have argued that BASF offered Nernst an annual "honorarium" of 10,000 marks for 5 years and, that afterwards, Nernst considered it "a national duty" to defend Haber's patent which had previously been questioned. Additionally, the group exhibited some weaknesses related to understanding of chemical knowledge and to the fact that working in collaboration is a characteristic of science (see the PSTA used as example in the section describing the methodology of the analysis). This PSTA shows a lack of understanding that the prize was awarded for the synthesis in the conditions in which it took place. Furthermore, other scientists should have been cited and recognised as collaborators. Instead, the group emphasised that the fact that other scientists had worked on the subject made Haber's work less deserving.

The Defence group based their initial PSTAs on four themes:

1. *Haber was a great scientist.* Six PSTA related to this theme were presented, based on the following: the scientist's positive character (2), the emotional appeal (2), historical aspects (3). Of these arguments, only one had a strong piece of evidence.
2. *Haber was motivated to synthesise ammonia for noble causes.* Five PSTA related to this theme were presented, based on the emotional appeal (1) and historical aspects (4). Of these five PSTAs, only one had a strong piece of evidence.
3. *Haber's work was conducted in collaboration with industry and received invaluable assistance from it.* Only one PSTA based on history was presented, with a strong piece of evidence.

4. *The Nobel Prize criteria.* Two PSTAs were presented, one based on the criteria for awarding the Nobel Prize and the other based on a related historical aspect, both with strong evidence, as presented in this example:

   The Nobel Prize is **awarded to people who have made significant contributions to the development of science and humanity**. To get an idea of Haber's importance to the development of humankind, suffice it to say that <u>the amount of nitrogen released by natural processes was not enough to produce food for the entire world population, which was growing.</u> [Defence, Nobel Prize criteria & history]

The Defence group did not provide explicit justifications for their PSTAs. Unlike those of the Prosecution group, the PSTAs from the Defence were more diversified and focused on the problem, with less emphasis on the emotional appeal. PSTAs based on scientific aspects, which could have been decisive for the group, were not used.

During the final discussion of the activity, when our analysis was presented to the pre-service teachers, we highlighted all the inconsistencies in the arguments they had proposed. One of the problems we highlighted was the exaggerated use of arguments related to the emotional appeal. For example, we emphasised that a large problem for the Prosecution stemmed from basing its reasoning on an argument which in turn relied on an emotional appeal and a false foundation, in other words, using the criteria for the Nobel Peace Prize rather than those applying to the award for chemistry to justify not awarding the prize to Haber. Consequently, all the eloquence used in presenting their arguments was unsubstantiated. We also highlighted the problems arising from the failure to use arguments based on scientific knowledge, and we showed several examples that could have been used by both groups to "win" the initial phase. We finished this part of the discussion by noting that both groups demonstrated positive and negative points, and that neither one stood out as more convincing than the other.

Table 3 Summary of the argumentation in each stage of the trial

Group	Summary of the PSTA	Initial	Reply	Rejoinder
Prosecution	1. Haber was a human being without character (nationalistic, militaristic, inhuman, egocentric)	x	x	x
	2. Other scientists had already synthesised ammonia, i.e., Haber was not the first to do so	x		
	3. Haber denied knowledge of previous work	x		
	4. Haber didn't work alone; he was merely a collaborator	x	x	x
	5. Giving Haber the award goes against the criteria defined by Nobel for the winners of the prize	x		
Defence	1. Haber was a great scientist	x	x	x
	2. Haber's studies were motivated by noble causes	x	x	x
	3. The work was done in collaboration with (and with invaluable assistance from) industry	x		
	4. Awarding Haber the prize meets the criteria set by Nobel for this award in the field of chemistry	x	x	
	5. Haber was not a bad person; he was defending the interests of his country		x	
	6. Science cannot be characterised as morally good or bad. The use of scientific knowledge cannot characterise science		x	

Table 4 PSTAs refuted at every stage of the trial

Group	Summary of the PSTA	Reply		Rejoinder	
		OK	At	OK	At
Prosecution	1. Haber was a human being without character (nationalistic, militaristic, inhuman, egocentric)	D	–	–	–
	2. Other scientists had already synthesised ammonia. That is, Haber was not the first to do so	D	–	D	–
	3. Haber denied knowledge of previous work	–	–	–	–
	4. Haber didn't work alone; he was merely a collaborator	–	–	D	D
	5. Giving Haber the award goes against the criteria defined by Nobel for the winners of the prize	D	–	D	–
Defence	1. Haber was a great scientist	–	P	P	P
	2. Haber's studies were motivated by noble causes	P	P	–	–
	3. The work was done in collaboration with (and with invaluable assistance from) industry	–	–	–	–
	4. Awarding Haber the prize meets the criteria set by Nobel for this award in the field of chemistry	–	–	–	P
	5. Haber was not a bad person; he was defending the interests of his country	–	P	–	P
	6. Science cannot be characterised as morally good or bad. The use of scientific knowledge cannot characterise science	–	–	–	–

At = attempt to refute that were not successful; D = PSTA refuted by the Defence; P = PSTA refuted by the Prosecution

Part B: Reply and Rejoinder

In Table 3, we present a summary of the themes used in argumentation by each group in every stage of the trial. Table 4 shows which of these PSTA was refuted in the reply and rejoinder stages.

The Prosecution presented only five PSTAs of types 1 and 4 (Table 3) during the argument in the reply, based on: emotional appeal (4), the scientist's (negative) character, (3) and historical aspects (3). Once again, the Prosecution group intensively used emotional appeal as a strategy for argumentation. All the evidence presented by the group was strong. Only one justification was presented, and it was also strong. However, the relationships between the claims on the one hand and the evidence and justification on the other were generally weak or vague. There were attempts to refute three of the Defence group's arguments, but only in one case was this rebuttal satisfactory (Table 4). For example, the Prosecution presented a PSTA against the evidence presented by the Defence about Haber being a genius and the fact that he studied alone:

> **In developing the synthesis of ammonia, Haber was a mere collaborator**, *since his own knowledge was not enough.* Researchers like le Chatelier and Bosch were fundamental to the success of the process. *The knowledge used by Haber was already known to others.* We can only say that **Haber was just a good leader**, not worthy of a Nobel Prize in chemistry. Maybe a Nobel Prize in economics would suit him better. [Prosecution, reply, historical aspect].

In this case, the justifications and evidence are strong, but the relationships with the claims are weak. The inference about the Nobel Prize in economics does not seem to make sense. Yet again the group members showed a lack of clear and detailed understanding of the scientific aspect, as they only talked about Le Chatelier and Bosch, while omitting other scientists who were significant in this context, such as Ostwald.

The Defence group presented 14 arguments, not including type 3 (initially presented), but rather using two new types (5 and 6). The bases of the argument were: historical aspect (12), emotional appeal (1), criteria for awarding the Nobel Prize (1), and nature of science (1). Again, the group based the argument on historical aspects. Of the eleven justifications presented, nine were strong. Of the four pieces of evidence presented, only one was weak. Only one argument presented both evidence and justification. Four arguments from the Prosecution group were refuted and, for the most part, these refutations were based on new information, as can be seen in the following example.

> As for whether he deserved the Nobel Prize, it is important to remember that **Haber was awarded the Nobel Prize for Chemistry, and not for Peace.** Therefore, *what must be considered is the scientist's contribution to the development of science and humanity*, and in this respect *there is no way to challenge the importance of Haber's studies on ammonia synthesis.* [Defence, reply, historical aspect]

The Prosecution group used the criteria for the Nobel Peace Prize instead of the Nobel Prize for Chemistry in the initial part. The Defence group opposed this argument, presenting a relevant justification.

The Defence had better arguments in this part of the trial, but the main arguments that would convince the jury that Haber deserved the award (which were scientific, that is, those which effectively showed his contributions) had not yet been presented in this part. This could raise doubts in the jury: after all, why were Haber's contributions so important?

As seen in Table 4, again during the rejoinder, the Defence group managed to refute more arguments than the Prosecution. They focused their argumentation on only two types of arguments (1 and 2, Table 3) but, unlike the Prosecution group, the Defence brought new aspects which were relevant to the situations and were more objective. However, the Defence group came up short again in detailing and highlighting Haber's scientific contribution. The Prosecution was more repetitive, used emotional appeal more as an argumentation strategy, and showed a more restricted understanding of the historical texts.

As in the initial part, the arguments presented by each group during the reply and the rejoinder were discussed with the pre-service teachers as part of the presentation of the jury's verdict. In this context, we took every opportunity to *explicitly* discuss the elements of the argument and the characteristics of NOS related to the case.

When presenting the conclusion of the trial, we highlighted the fact that the groups did not use scientific arguments, which would have been essential to the discussion in question. For instance, the Defence group could have emphasised the relevance of Haber's work by showing how difficult it was to produce ammonia, since this is an exothermic reaction, which means an increase in temperature favours the reverse reaction. On the other hand, due to the stoichiometry of the reaction, an increase in the system's pressure favours the direct reaction. Additionally, the direct reaction has a high value of activation energy. Therefore, it was necessary to conduct a complex study involving all the thermodynamics variables, which was exactly what only Haber was able to do. Scientific arguments like these were identified and explained to the pre-service teachers, emphasising what the function of each would have been in the positions held by each group. Another aspect we discussed was related to the quality of the argumentation. In this sense, we showed that there were few arguments presented along with evidence and justification. In other words, of all the PSTAs, only a few could actually be identified as complete arguments (with greater powers of persuasion), according to the literature.

Considering the dynamics of the mock trial, our view was that:

- in general, the Defence argued better, both in terms of preparing coherent PSTA as well as in preparing rebuttals that were effectively related to the PSTA presented by the Prosecution;
- although the Prosecution used five different themes in their opening arguments, the discussion was mainly concentrated on two of them;
- during the replies and rejoinders, at times the Prosecution tried to misrepresent the arguments of the Defence, but was unable to see their weaknesses (which, if well articulated, could have been used by the Prosecution);
- throughout the process, the Prosecution used emotional appeal much more than the Defence did.

Therefore, considering the argumentative aspects, the Defence group would be the winner of the trial. But, despite the fact that they argued better, the Defence did not present arguments to show and to convince the jury that Haber was responsible for the most important recognised discovery (or improvement) in the area of chemistry in 1918 (main criterion used to award the Nobel Prize). Therefore, in a real situation the non-use of scientific arguments (which would effectively persuade the jury that Haber's work was brilliant and worthy of the award) would cause the trial to be postponed, in order to give the two parties more time to submit more convincing evidence.

Despite some problems constructing and using the PSTA, our analysis shows that the pre-service teachers' involvement in the activity resulted in a rich argumentative situation that was significant for their development, as discussed in the next section.

4.3 RQ3: How Do Pre-service Teachers Assess the Contribution of Discussing a Controversy Related to the History of Science to Their Future Work as Teachers?

Both in the final moments of the videos of each meeting, as well as in the reflective journals, we found a variety of evidence that the pre-service teachers reflected not only on the controversy itself and on the characteristics of science related to it, but also on their future work as teachers. Some examples:

> Today, after all the discussions, my view of science has changed a lot. Initially, like most people, I thought it was a waste of time to teach the history of science to high school students. Today, I see how important it is to humanise science, to bring it closer to the students' reality and, in doing so, boost their interest. We also must be very careful about the way this content is presented in textbooks. Most of the books rescale history in order to show only what worked in producing scientific knowledge. But one of the main goals of teaching the history of science is to bring it closer to the reality of the students, and this goal will not be reached if we do not show that, in the process of building scientific knowledge, scientists made mistakes until they reached what we study today; they had the help of other scientists; and science is a process of building and improvement and not an absolute truth. Only then will they abandon the idea of science as something unattainable and discover that anyone who wants to can become a scientist, including themselves. [Pre-service teacher 2 from the Defence group]

> Studying history for me was a bit complicated, since I thought it was hard to make connections between the subjects we looked at; they seemed to be disconnected stories. But Haber's story and the entire context involved were completely connected. It becomes possible to realise how things do not happen by chance; but it is as if things were responses to other events. So I understand how the history of science, the history of the world should be told in a way that makes sense for the student, and that there should be a relationship between the issues that permeate history. [Pre-service teacher 4 from the Defence group]

> I was thinking how beneficial it would be if high school students knew about the Haber story, because that might humanise science, that is, bring it closer to human beings. It could be used to discuss ethical, economic, and social issues. [Pre-service teacher 4 from the Prosecution group]

> The dramatisation was a very good example of how to approach the history of science and about science in the classroom in order to make educational content more interactive, creative, playful. By humanising science through history, students become a lot closer to it. This gives meaning to learning since they see that scientific knowledge is not only a tool that lets them ascend socially and economically, but instead broadens their culture, making them citizens who know how to act critically and reflectively in society, and who can take positions based on their conceptions and convictions. [Pre-service teacher 7 from the Prosecution group]

> In general it was a great experience. From it I was able to conclude that some stories, like the one about Haber, if they are brought into teaching, can show the students that there are certain controversies in science and that it does not happen in a linear way. [Pre-service teacher 8 from the Prosecution group]

As highlighted by Bell, Lederman and Abd-El-Khalick (1998), we cannot believe that it is enough to promote the development of knowledge about NOS in pre-service teachers and to hope that this has a direct impact on the teaching that they produce (and even the literature does not support this idea). For example, Demirdögen et al. (2016) analysed the development of pedagogical content knowledge (PCK) among pre-service chemistry teachers involved in a situation of explicit and reflective teaching about NOS. These authors stressed that teachers need not only prerequisite knowledge and beliefs to teach NOS, but they also must be satisfied with their own understanding of NOS in order to teach it. The broad view of science expressed by the pre-service teachers completing their teaching degree (Table 2) and the very clear and justified explanation of the intention to introduce such aspects *about science* into teaching (as presented in this session) are essential steps for these pre-service teachers to be truly motivated and dedicated to the activities that can help transform their knowledge about science into other knowledge and skills that can effectively support their future work as teachers.

5 Final Considerations

In this article, we sought to contribute to research and teaching by presenting an analysis of argumentation by pre-service chemistry teachers who participated in a historical dramatisation—an activity that had potential for supporting the explicit teaching of both NOS and argumentation.

Our results indicate that the pre-service teachers' involvement in the activity of judging a dispute related to an event in the history of science helped them to broadly understand several aspects of science and the production and use of scientific knowledge. The pre-service teachers highlighted aspects that characterise their views of science as broad, such as the funding of scientific research (an aspect related to the economics of science; Erduran and Mugaloglu 2013; Irzik 2013), the role played by publications in science (an aspect related to communications in science; van Dijk 2011), the individual character of the scientist, in this case Haber's perseverance in pursuing his research and his brilliance (an aspect related to the psychology of science; Feist and Gorman 1998), and the collaboration between scientists and companies to produce scientific knowledge (an aspect related to the sociology of science; Cunningham and Helms 1998). Aspects of science studied by various areas, such as the psychology of science and the economics of science, for example, have not been widely explored in science education. The pre-service teachers were not informed in advance about these characteristics of science; in other words, these characteristics emerged from the context, which supports studies that defend the relevance of teaching NOS based on using episodes from the history of science (Allchin et al. 2014; Braga et al. 2012). In this way, our results corroborate the position of Justi and Erduran (2015) about providing the students and the teachers with the possibility to view science from various areas and viewpoints in each knowledge area. Such a broad understanding of science supported the explanation of reflections by these teachers about aspects that should be considered in their future teaching practices in order to promote more authentic science education for their future students.

The context designed to promote argumentation among the pre-service teachers, which involved a provocative question related to a controversy over a historical event, was very successful in creating an argumentative environment. This can be seen in how the teachers produced their arguments using different bases and also from the way they engaged (their tones of voice, costumes, the roles they played, and analysis of the other group's argument) while presenting their opening arguments and during the reply and the rejoinder. Thus, the study presented here is in line with other studies that demonstrate the relevance of using controversial issues (which are difficult to resolve without insightful analysis of evidence and consideration of opposing and supporting arguments) in promoting argumentative situations (Allchin et al. 2014; Archila 2015; Jiménez-Aleixandre and Pereiro Muñoz 2002).

In terms of argumentation, the literature points out the difficulties that students and science teachers have with argumentative skills in various contexts, for example, analysing evidence, arguing based on evidence, connecting evidence and justifications in an argument, using more than one piece of evidence to persuade, refuting opposing arguments, etc. (Simon et al. 2006; Vieira et al. 2015; Zembal-Saul et al. 2002). Our analysis also showed the problems that pre-service chemistry teachers have with argumentation. For example, only a few of their PSTA connected evidence and justifications. In addition, the pre-service teachers demonstrated difficulties in formulating arguments sustained by knowledge of chemical aspects involved in the process of producing ammonia. However, during the discussions, they themselves expressed doubts about the understanding of the conceptual aspects involved in the texts (such as chemical equilibrium and Le Chatelier's principle). The literature has highlighted the relationship between conceptual understanding and formulating higher-quality arguments (Mendonça and Justi 2014; von Aufschnaiter et al. 2008). Therefore, we can infer that the difficulties the pre-service teachers had in understanding the scientific content involved in the controversy was one of the reasons they had difficulties in producing better-quality arguments based on these principles. The results of the quality of the arguments obtained in this study may also reflect the fact that the pre-service teachers demonstrated some problems in understanding the scientific knowledge involved, as well as the fact that this was the first time they participated in an activity involving role-playing in a mock trial. Furthermore, most of them had had very little previous contact with historical texts; in other words, this type of analysis was new for them. Accordingly, the results of this study reinforce the need for teachers to have the opportunity to develop argumentative skills in a variety of distinct contexts and at different stages of their training (Simon et al. 2006; Zembal-Saul et al. 2002).

The presentation and discussion of the trial verdict, when we analysed each PSTA used in each stage of the trial and we shared the explanations of the judging criteria, comprised a methodology for explicit teaching of argumentation. This proved to be very fruitful, since it generated several productive discussions between the teacher educators and the pre-service teachers based on the examples the pre-service teachers proposed. For example, the meanings of argument, evidence, and justification became more palpable to the pre-service teachers based on the examples discussed.

Considering the relationship between aspects of NOS and argumentation, analysing the trial showed where the view of science influenced an argument and where a given argument showed pre-service teachers' understanding of science. In the case of the Prosecution group, claims like *Haber didn't work alone* can be seen as a sign of a lack of understanding about collaborative work in science. In the case of the Defence, the argument that emphasised the distinction between how humans use scientific knowledge and how science can be characterised as morally good or bad also indicates the group views science as being free of values. On the other hand, this also betrays a possible weak view on the part of the Prosecution with regard to this aspect of NOS, since the Defence used this kind of argument to refute the arguments against awarding Haber the Nobel Prize based on the use of knowledge derived from synthesising ammonia used by the Prosecution. As mentioned, there are still few studies examining the relationship between argumentation and nature of science (for instance, Abi-El-Mona and Abd-El-Khalick 2011; Archila 2015; Khishfe 2012, 2014; Sadler et al. 2004). In addition, some cast doubt on whether the epistemological view of subjects influences their arguments, or if the opposite occurs (Sandoval 2005; Sandoval and Willwood 2008). Sandoval (2005) affirms that providing students with the opportunity to experience investigative activities in which they have to clarify their epistemological views is the best way for us to understand their argumentative reasoning. In our study, the types of activities in which the pre-service teachers were immersed were seen to be fundamental to both supporting (i) their understanding of science; (ii) their explanation of it through their PSTA, and demonstrating how the view about science impacted the content of these arguments.

Studies that investigate the contributions of the use of historical episodes in teacher education contexts and in science classrooms, with the goals of studying their influences in developing argumentative skills and clearer views of NOS, and especially in the relations between NOS and argumentation, are promising for the field of science education. This is due to the fact that they can foster more discussions, such as those presented in this article. Despite our good results (as most of the pre-service teachers from both groups improved their views), we recognise that the intervention discussed here was short and limited in terms of the aspects of NOS that can be discussed. However, this was only part of a larger project. Subsequent discussions emphasised both the aspects discussed here as well as others that have helped to consolidate and enlarge the view of science among pre-service teachers.

We also recognise that much more needs to be done to encourage the development of PCK among pre-service teachers. In particular, they should be involved in planning and conducting teaching activities, where the teaching of aspects of NOS is among the objectives. This also occurred in later steps of the project, when the pre-service teachers did a long internship in regular classrooms, conducting activities that had been planned after participating in the activities related to the mock trial.

Regardless of the limitations of the activities which have been discussed herein, we emphasise that our data show that participation in these activities contributed to the personal, social, and professional development of the pre-service teachers, aspects which were indicated by Bell and Gilbert (1996) as essential in teacher development programmes. This is because the pre-service teachers (i) emphasised in their reflective journals how much they learned by actively participating in the activities and how much more secure they felt in relation to the need to include aspects of NOS into their future teaching work; (ii) had several opportunities to discuss all their ideas, questions, and uncertainties with their colleagues and with the entire group in an environment that aimed to foster each one's learning. In particular, the involvement in the joint production of arguments and the various stages of the trial meant a rich collaborative work experience; and (iii) demonstrated that they learned a lot about the history of science, nature of science, and the role that each one can play in authentic teaching *of* and *about* science. For each of these aspects, which together constitute a solid basis to start developing PCK among these pre-service teachers, further analyses will be discussed in the future.

Acknowledgments The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq, for the financial support for conducting the research project from which this article originates; the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES, for supporting the pre-service teachers who participated in that project; and the members of the "*REAGIR*: Modelling and Science Education Research Group" for contributing in the design of the activity analysed in this article, the data collection, and the data analysis.

Conflict of interest The authors declare that there is no conflict of interest.

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