Nature of Science Knowledge and Astronomy Workshops: A Case Study

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ABSTRACT: Astronomy, astrophysics, and cosmology workshops represent a way for students to better understand the nature of science. In this paper we have analysed the development of this kind of workshop organized in Argentina. This is qualitative, holistic, and interpretive research. We have found this to be a way for students to become aware of modern science and to understand how science is built today, recognizing its daily growth, and it is an introduction to the way science works. Students come to recognize science as developed by humans, an image of science closer to the fictional view than that often shown in textbooks and by science teachers.

FRENCH ABSTRACT

Introduction

The initial question often asked is "why is it so important that students know about the nature of science." We are living in a knowledge society in which the educational requirements are presently more demanding. Scientific education occupies an important place in student training. Analysing the usual high school curricula in natural sciences, as occurs in physics for example, we notice that it shows primarily a technological approach. We did not find a historical contextual presentation of the topic as we would hope to in a historical philosophical approach (Reis, Guerra, Braga, & Freitas, 2001). The focus of the technological approach is strongly oriented to the mathematical application of physics problems. It appears that students and teachers often look only for results and in this way physics is changing into boring work where students only solve useless problems (Santilli, 1995). In this way, students think about science as certain and mathematically exact, with only one solution to a problem, without considering other possibilities – like timeless science, not contextual science, and so on. When we want students to understand science, it is not enough to ask them to study scientific laws and theories. Students also need to understand the nature of science. Besides teaching the technological and mathematical aims, it is necessary to present science framed by cultural, social, and philosophical commitments (Matthews, 1998, 2000).

It is possible to find reasoning to justify the necessity of teaching about the nature of science. Driver, et al. (cited in Brickhouse, Dagher, Shipman, & Letts, 2002, pp. 373, 374) presents five different kinds: utilitarian, democratic, cultural, moral, and science learning arguments. An utilitarian argument could be defined as: "an understanding of science is necessary if people are to make sense of the science and manage the technological objects and processes they encounter in everyday life" (p. 373); this argument is essential for development of the cited "scientific-technological alphabetization." Driver enounces a democratic argument as: "an understanding of the nature of science is necessary if people are to make sense of socioscientific issues and participate in the decision-making process" (p. 373); this is fundamental if our purpose is to teach science and to educate the citizenry. The cultural argument is based on the fact that science is part of culture; it is not possible to think about contemporary culture without science. Concerning a moral argument Driver says: "an understanding of the nature of science can help develop awareness of the nature of science, and in particular the norms of the scientific community, embodying moral commitments that are of general value" (p. 579). Finally, but not of less importance, Driver presents a science learning argument as: "an understanding of the nature of science supports successful learning of science content" (p. 574).

When considering another way of reasoning, we can analyze the role of models in the natural sciences. We have to recognize the existence of multiple models for a real system, and that the relationship between reality and theory is always mediated by a model. Then, the notion of the model is central to understanding and developing the natural sciences (Lombardi, 1999). Although models are referred to in science and in science teaching, they are not always understood in a proper way, in the practice of science or the philosophy of science. Another reason for developing students' knowledge of the nature of science is cited in the words of Matthews (2007, p. 650): "[the] nature of science knowledge (NOS) will involve learning something about the functioning of models in history of science, and something about their epistemological import." In this way, learning about the nature of science helps students gain a better understanding of scientific contents.

How can students learn about the nature of science? Science teachers must be careful to present not only their own point of view concerning science. Students are close to learning about the nature of scientific knowledge when they are able to choose freely from different points of view. Matthews (1998, p. 995) affirms: "to my mind, the nature of science is best approached inductively and tentatively, not didactically." He proposes several methods such as the discussion of episodes in the history of science, laboratory exercises, science-related social issues, and so on.

The organization of astronomy, astrophysics, theoretical physics, and cosmology workshops represent another method for students to recognize the nature of science. These workshops allow students to perceive ways in which scientists developed scientific knowledge. Astronomers speak about observations, dates, and evidence. The evidence can be observational, direct, inferential, or mathematical. They use complex technologies to collect observational data, a theoretical framework that is far above the knowledge of most high school students or introductory university course students. During the workshops teachers must be careful to allow students to come to a full understanding of this framework. When this learning obstacle is overcome, students find meaningful explanations in the astronomer observations.

Astronomy workshops can also help students to discover the relationship between theory and evidence, warrants for belief, and the nature of observation, and from this, students may come to a better understanding of the nature of science. Here, we start from a strong supposition: when students study subjects that are interesting and meaningful, they come to a stronger knowledge of the nature of science. This is not a shared supposition with the entire community. Some researchers assume that students' knowledge about the nature of science is independent from the scientific content studied (Brickhouse, et al., 2002).

A history of science can help students understand the relationship between the work of astronomers and the nature of science. An interesting case concerns Galileo and the discovery of Jupiter's moons. Galileo knew that there were three kinds of sky bodies: fixed stars, planets moving around the sun, and moons moving around the planets. He framed these known facts into a general hypothesis. He contrasted his own observations against these hypotheses and drew conclusions using hypothetical-deductive reasoning such as astronomers do today (Lawson, 2002). Other researchers question this position – Allchin affirms that "there is no historical evidence that Galileo developed such an explicit prediction, built the telescope, and directed it at each Planet in turn specifically to search for the predicted moons" (2006, p. 99). He is referring to Galileo and the discovery of Jupiter's moons. We agree with Lawson's interpretation in spite of this lack of historical evidence since this interpretation is closer to Galileo's facts, behaviour, and thoughts. Moreover, this interpretation could help students to understand Galileo's method of working.

From another point of view, we agree with Price (1963) who considered through analysis that, from a historical perspective, either Galileo's or Planck's facts made it is easier to understand scientific processes, than by use of methods of contemporary scientists.

The use of history of science (HOS) for students understanding the nature of science (NOS) presents different results from science teaching research. These differences apparently depend on the way in which history of science is presented.

> The variety of results in the implicit and explicit ways of using HOS for students understanding of the NOS suggests that there is a need for more detailed description of the teaching strategies rather than implicit or explicit ways of teaching the NOS. (Seker & Welsh, 2006, p. 85)

Astronomy Workshops in Argentina: A Case Study

In Argentina, astronomy topics are only lightly covered in high school curricula or in university introductory courses. This situation may have several reasons: these topics are almost completely absent in school curricula, the experimental work is difficult to cover in teaching institutions, it is necessary to spend a great deal of time explaining these topics, it is difficult to find appropriate teachers, and so on. The extracurricular approach to these topics allows the introduction of outstanding scientific knowledge, different ways of scientific work, new technology and data analysis, and interpretation systems.

In this paper we have analyzed the development of astronomy workshops which have been organized since 2002 at IAFE (Instituto de Astronomía y Física del Espacio – Institute of Astronomy and Space Physics). The workshops are co-ordinated by scientists of the Institute. In the workshops subjects such as astrophysics, astronomy, cosmology, relativity theory, quantum physics, and so on are covered.[1] There students find answers to the question: "How do astronomers work in Argentina today?" They discover where today's Argentine astronomers are positioned, between middle age astronomers and Hubble's researchers.

Workshop Characteristics

The workshops are intended for high school and university introductory course students. Common goals for students are defined as:

- better vocation choices;
- to gain an understanding of astronomy, astrophysics, and cosmology topics;
- to comprehend ways of researching these topics;
- to be make contact with researchers; and,
- to gain an awareness of modern science.

The workshops are held once a week – a three-hour class, and between twenty and thirty students attend each class. The number of classes depends upon the workshop. For example, the workshop: "Introductory Astronomy" consists of four classes (the solar system, stars and sun, star systems, and the universe); and the workshop "Relativity and Cosmology" consists of between five and seven classes (some of the topics are history, elemental concepts about relativity theory, an historical introduction of cosmology, black holes, and the Big Bang). Workshop teachers cover the subjects using Power Point presentations that include movies and simulations to facilitate understanding. Dialogue expositions allow students to pose questions. Teachers pose problems or a paradox to be solved by students. The workshop environment allows students to present their doubts and questions. This is an important aspect of the workshop organization because it represents a good place to develop meaningful negotiation and appropriation processes necessary for learning. Meaningful negotiation allows students to present their own beliefs. These kinds of activities,

> Allow for the potential renegotiation and restructuring of students' conceptions related to the science learning activity. The objective of both meaningful negotiation and appropriation is not only to transform the nature of what learners know, but also for them to

> understand how they come to know what they know. (Duschl & Hamilton, 1998, p. 1053)

Students obtain a workshop certificate with 80% participation. They can ask for a formal test, if they wish, and can apply to become student assistants to the researchers.

Research Methodology

This is a qualitative, holistic, and interpretative research since we try to rescue student's ideas. This is supported by the supposition of reality as a social construction where the researcher tries to interpret the subjects' sayings and attitudes. In this process, the researcher interacts with the researched subjects, affecting this construction (Alves, 1991). This approach allows for the social aspects of learning.

The research is exploratory in nature and the goal is to try to find out if students actually learn about the nature of science at astronomy workshops. This approach used a case study (Alvarez-Gayou, 2003), the most important qualitative research method. We describe here a particular situation, but it may be possible to classify all the categories we found into a database where anybody could access the information. If published it would provide a good science teaching database of case studies, dispensing an adequate knowledge frame (Santilli & Speltini, 2007). In the words of Keeves':

> Case study research is not restricted to the investigation of a single case from which any attempt to generalise would be impossible. The development of multi-site case study procedure, involving the use of case study methodology across many settings, permit generalisation to be made. (1998, p. 1143)

Lemke (1998, p. 1184) analysing the importance of verbal data for science education research says: "longitudinal designs or case studies are well suited for discourse analysis methods because we can learn a great deal about a particular class, seeing repeated patterns within the data and a variety of strategies which create variations on those patterns." Both researchers confirm the interest of case study methodology for inquiry about students' nature of science knowledge.

The data analysis emerges from student answers to open inquiries. These are high school and university level introductory students, aged between 15 and 19 years. They have pre-scientific and little assimilated scientific knowledge.

We must explain that this inquiry was designed to test the workshop goals, not for analysing students' nature of science knowledge. But students' answers allowed us to complete this research. We analyzed over 90 inquiries from 2002 to 2003. Some of the inquiry questions were:

- Did you carry out the workshop expectations?
- Was the form of the workshop appropriate? Why?
- What other questions would you want to know about the IAFE?
- Did the workshop help you to gain a better vocational choice? Why?

Comments and suggestions about the workshop and the topics developed.

The data were analyzed associating each student response into a category. We then used a qualitative software program called NUDIST. This system helps with the organization of qualitative data. It allowed us to assign and to codify categories, to do searches, intersections, unions, and so on. It is a helpful tool for qualitative research, especially for a very large data analysis. It is possible to start from known categories, or to allow the categories to emerge from the data. As this was an exploratory research, the categories emerged from the student responses.

Triangulation was done in two ways: a) Instrument – different questions of the inquiry aimed at the same subject, and b) Investigator – two researchers were involved in this state of the investigation. One was in touch with the students and helped the scientists with the organization of the workshop, the other researcher analyzed over a period of time students' ideas about science.

Research Results

We found that students' responses were mostly divided into two main topics: scientific research and scientists' way of working.

Regarding the main topic "scientific research" students' expectations were identified into three categories: *material things*, *methodology*, and *projects*. Next, we defined each category and selected some student responses relating to the category. We identified each student response with the letter 'S' and a number.

Material things related to students who associated the research with laboratory work; they were concerned with the instruments used, the laboratory installations, and so on. Examples of students responses follow:

> *S3: I want to know how they do the research, what tools and devices they need. I also want to know in what other places an astronomer works.*
>
> *S16: I want to know more about radio-astronomy, and in what places there are big telescopes.*

Methodology was associated with students who were concerned about data processing, analysis of results, researchers' ways of working, and so on. Students who wanted to think as scientists do. Examples of student responses:

> *S20: How they process the information and how they organize the Institute's library.*
>
> *S25: The research, the projects that are developed today, and obtaining results.*
>
> *S27: The workshop teacher asked us scientific questions, they are inviting us to think as scientists'.*

Projects was defined as students interested in the projects that are developed at the Institute (IAFE). Student responses:

> *S97: We want to know, in detail, how the researchers work at the IAFE; in what astronomy fields of knowledge they develop their research.*
>
> *S102: To know the research, the projects they are developing today at the Institute.*

The second main topic "scientists' ways of working" was broken down into two categories: *society* and *profession*. Next, we define each category and select some student responses from it.

Society. Students were concerned with the work environment, the performance of the Institute, the researchers' incomes, the astronomer's personal life, and so on. Student responses follow:

> *S9: I'd like to know, what is the role of the Institute, and who leads the institution.*
>
> *S21: To know how researchers work, and if their incomes are enough to make a living.*
>
> *S82: The teacher exposition was clear and concise. It enriched our knowledge and personal experiences from the researchers that work here.*

Professions. Students were interested in researchers' work, in the scientific way of working, the working places, and so on. Responses were:

> *S2: I want to know about the research and the professional work, today, either for astronomers or physicists.*
>
> *S80: The class was good for me because it was an understanding and complete class. Moreover, I got from it, a vision of the astronomers' life and way of working.*

Some students' ideas were associated with the scientific explanations, laws and theories, or the students' scientific vision. There were just a few further responses, which we thought were important from this research:

> *S10: We could learn the stellar phenomena or the astronomical ones by using physical explanations.*
>
> *S28-29: The participation of everybody at the workshops allows us to deduce for ourselves some of the laws that rule the universe. Moreover when we learn astronomy, we understand how science works: scientists begin stating a hypothesis and then they try to prove it.*
>
> *S164: Cosmology for understanding how man gets knowledge from the beginning of science. We could understand in which way man's ideas about the cosmos have been changing.*

An interesting response was the student idea of learning scientific topics from physics explanations (S10). This idea is close to the conception of science as explicative: science explains what happens in nature (Simon, 1978).

In reference to laws and theories we find at the beginning of S28-29 response that there appears the idea of scientific laws governing a pre-organised deterministic universe. "The notion of implacability moreover, is a recurrent theme in the views of students concerning laws" (Désautels & Larochelle, 1998, p.117). But, in the second part, the student recognises that science has been developed built by humans. This last idea appears in the S164 quotation, where the student recognizes that man can change the theories. This idea is in agreement with other researchers: "Theories are contingent, and therefore subject to change" (Désautels & Larochelle, 1998, p.118).

Conclusions

When we analyzed students' participation we found students had a great commitment to the workshops. Some of them asked for formal testing and to be considered as student assistants to the scientists. Of course, it was only a possibility for students, but the number of students that made the request was larger than we had hoped for. On the other hand, we noticed, from the inquiry analysis, that they provided a great number of interesting suggestions for improving the workshops, teaching suggestions, the activities, or other topics to develop.

Concerning the nature of science knowledge, we found the first idea coming from the emerging categories. The main ones show that students' ideas were especially oriented in two ways: research and social aspects about science. We noticed that a few students had ideas about scientific explanations, laws and theories, or science vision. Then, we tried to interpret students' responses further. We deduced a special student vision about science from ideas expressed as: "*they process the information and how they organize the Institute's library*," "*they are inviting us to think as scientists,*" "*I could get there, a vision of astronomers' life and way of working,*" "'*The participation of everybody at the workshops allows us to deduce for ourselves some of the laws that rule the universe,*" "*We could understand the ways man's ideas about the cosmos have been changing.*" These ideas show that the activities involved in the workshops allowed students to be more aware of modern science. They came to understand the way science has developed today, recognizing its daily growth, and as an approach to the scientific way of working. These ideas are far from inductivism which affirms that the knowledge emerges from public observation without having in mind any theoretical frame. Inductivism assumes that the scientific way of working is the experimental verification of laws and theories (Brown, 1998; Chalmers, 1976). We paid special attention to the few inductivist ideas expressed, ideas included under the category titled *Material things*. There, the students were concerned with the experimental conditions, the kind of telescopes used, the laboratory work, and so on. This last result does not agree with other published researches. Most specialists affirm that young students present empirical, inductivist, and no theoretical ideas about science (Désautels & Larochelle, 1998; Fernández, et al., 2002). Moreover, inductivist ideas are present in some science teachers and student teachers of science, as shown by other researchers (Abell & Smith; Brickhouse; Cotham & Smith, all cited in Porlan & Rivero, 1998; Aguirre, Hagerty & Linder; Ballenilla; Benson; Currais & Pérez; Duschl & Wright; King; Loving; Porlan; Powell; Rubba

& Harkness; Rugeri, Tanzani & Vicentini, all cited in Mellado, 1998; Désautels & Larochelle, 1998; Hodson, 1986; Santilli & Speltini, 2005).

In both the categories, *Society* and *Profession*, we identified interesting comments related to daily scientific work. From this point of view, the participation in the workshops allowed the students to recognize science as developed by humans, an image of science more accurately portrayed in the fictional view rather than textbooks and teachers of science often offer (Santilli, 1997a, 1997b). This result also does not agree with other researchers. Students do not recognize socio-political or economic questions that affect scientific practice. They usually think about science as a cumulative series of investigations, logically related to each other. Students seem to think about the scientific community as a "collection of individuals than as a social practice in which a network of actors and alliances is at work" (Désautels & Larochelle, 1998, p. 121). This idea of science helps them in two ways: students can better understand scientific contents, and they can make better vocation choices. We could speculate that this situation was because students were in touch with scientists, but we did not consider this as part of our inquiry – it could be a topic to pursue in further research. Our strongest conclusion is that astronomy workshops are a very good place to expose students to a scientific way of working and to learn about the nature of science.

NOTES

1. Additional information is available on www.iafe.uba.ar (Extensión; Talleres de Ciencia para Jóvenes).

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